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FINAL REPORT

VOLUME I

HYDROLOGICAL SURVEY OF IRAQ

MAIN REPORT

A REPORT BY

HARZA ENGINEERING COMPANY
CHICAGO

BINNIE & PARTNERS
(FORMERLY BINNIE, DEACON & COURLEY)
LONDON

IN ASSOCIATION

PREPARED FOR

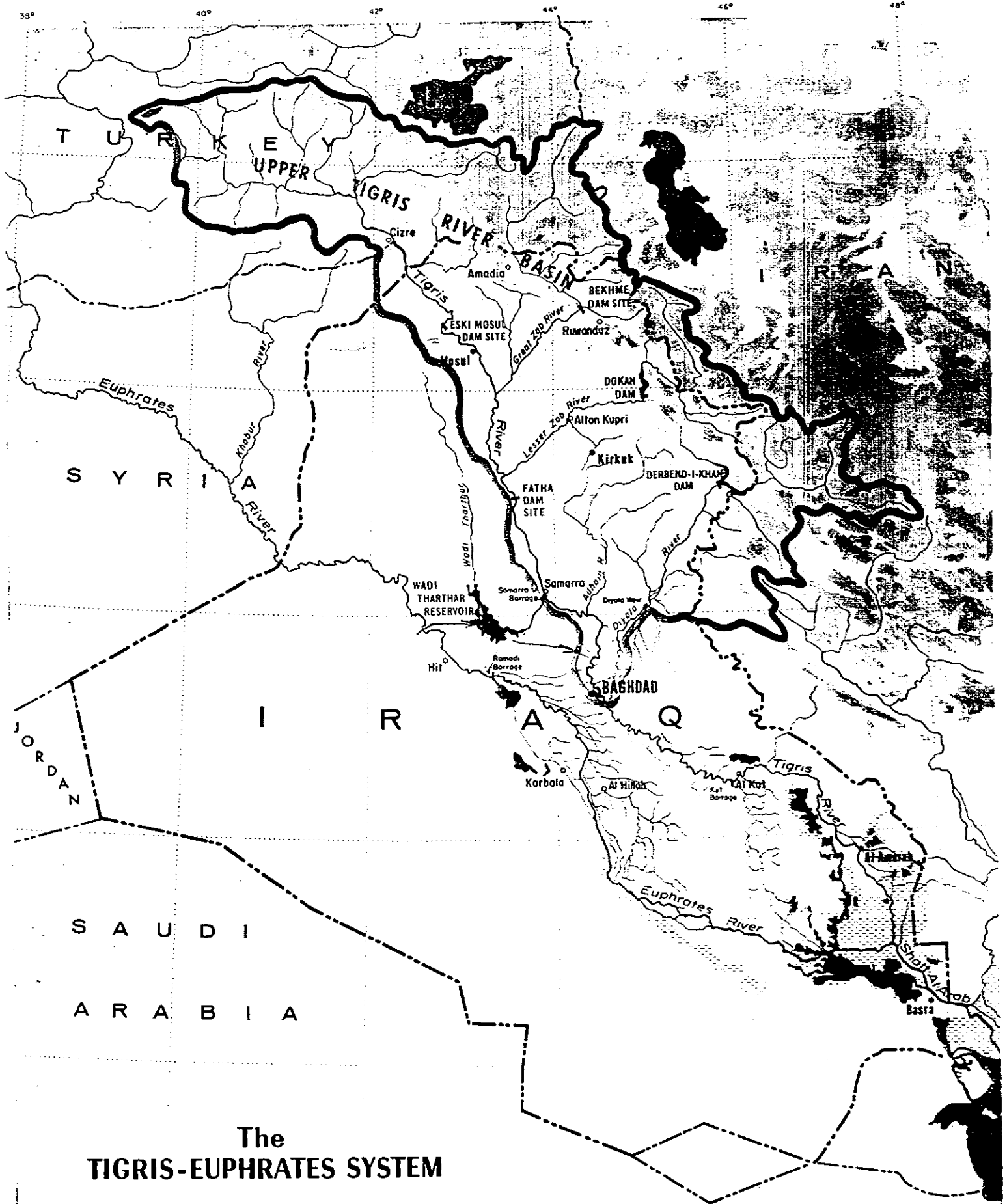
THE GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

BAGHDAD, IRAQ

JULY 1963

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A



The TIGRIS-EUPHRATES SYSTEM

Elevation in Meters
0 400 800 1200 1600 2000 2400 2800 3200 3600 4000

Scale in Kilometers
0 20 40 60 80 100 120 140 160 180 200

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Irrigation Operations

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v. 2. Appendix A. Hydrologic Network
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Appendix C. Flood-Control
Operations.
v. 4. Appendix D. Electronic Computer
Studies of Irrigation Operations.

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HARZA ENGINEERING COMPANY
CONSULTING ENGINEERS
CHICAGO, ILLINOIS 60606

June 15, 1964

Air Mail

Mr. Kenneth F. Vernon
Chief, Public Works and Industry Branch
NASA/Engr. Bureau of Near East and South Asia
Agency for International Development
Department of State
1901 Pennsylvania Avenue
Washington, D. C.

Subject: Hydrological Survey of Iraq - Final Report

Dear Ken:

Some last minute rearranging of Exhibit B and Table 7.4 of Volume I of the subject report resulted in several errors of tabulated data. These do not affect the remainder of the report in any way. Corrections were made in ink to most of the originally distributed reports.

Replacements for these two pages are enclosed for insertion in the copy of the report we sent you on November 1, 1963.

Very truly yours,

HARZA ENGINEERING COMPANY

V. A. Koelzer

Enc: 2 correction sheets

*correction sheets
inserted 10/15/64
VAK*

F

HARZA ENGINEERING COMPANY
CONSULTING ENGINEERS
CHICAGO

BINNIE & PARTNERS
CHARTERED CIVIL ENGINEERS
(FORMERLY BINNIE, DEACON & GOWRIE)
LONDON

IN ASSOCIATION

Director General of Irrigation
Ministry of Agriculture
Baghdad, Iraq

Subject: Report on Hydrological Survey of Iraq

Your Excellency:

We are pleased to present our Final Report on the Hydrological Survey of Iraq. It consists of this Summary Letter, the Main Report, and four appendices.

Summary of Assignment

The work we have performed has been in five general categories, as follows:

Phase I - Compilation, evaluation, and recomputation of existing data of river flows and meteorology in the Tigris and Euphrates river basins.

Phase II - Installation of additional stations for observing hydrologic data, including training of Iraqi personnel in procedures for obtaining and processing these data on a continuing basis.

Phase III - Determination of probable maximum floods in Iraq and probability of floods of lesser magnitude.

Phase IV - Evaluation of degree of flood control and of amount of water made available for irrigation and other use resulting from various combinations of existing and proposed reservoirs in Iraq.

Phase V - Development of guides and rules for operating reservoirs and recommendations for procedures to control the rivers.

Phases I and II involved extensive field and office work and furnished important basic data needed for Phases III and IV, as well as for future planning and operation. The reader is referred to Chapters 1 and 2 of the Main Report and Appendix A for further details.

This Summary Letter is concerned primarily with the results of Phases III and IV, which directly affect the planning of further development of Iraq's water resources. The investigations involved computation of flood potentials and studies of various combinations of existing and proposed water control structures to produce effective flood control as well as to meet the requirements of irrigation projects. Proposed dams at Fatha, Eski Mosul, and Bekhme and the utilization of Wadi Tharthar for irrigation storage were considered, together with varying heights of dams at the three damsites and varying elevations of the irrigation outlets at Wadi Tharthar. The many possible combinations of these alternatives were studied for flood control, irrigation deliveries, and power production. Almost 300 operation studies were made to compare system performance for the various purposes. Details of Phases III and IV are given in Chapters 3 to 7 of the Main Report and Appendices B to D.

The details of Phase V, given in Chapter 8, will be useful primarily as a reference in setting up the operational organization and in direction of future operations of the Tigris River System.

Flood Potential

A summary of our investigation of the flood potential of the Tigris River and its tributaries is given in Exhibit A. Our determinations of the probable maximum floods result from analyses of the storm and snow-melt potentials and characteristics of the sub-basins. The factual records of floods are too short for reliable computations to be made with these records alone. The probable maximum floods are several times the maximum floods recorded during the 57 years of partial or complete streamflow record. However, we consider that our computed

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values of the probable maximum floods are reasonable. We feel equally confident that the potential exists for moderately frequent floods that are substantially larger than the maximum of record.

The history of Baghdad includes reference to many floods since its establishment in 762 A.D., some of which according to descriptions must have been substantially larger than the maximum of the last 50 years. The histories of other rivers throughout the world are replete with references to floods that were "much higher than ever before," even when records extended for centuries. There are many instances of floods two or three times as large as the highest flood occurring in the previous 50 years, the duration of streamflow records in Iraq.

The records of floods at Mosul do not include floods of great magnitude. However, analyses involving comparisons with other tributaries in the Tigris Basin reveal a much higher flood potential than the 40 years of record might lead one to believe. It is our opinion that the maximum flood during the period of record (6000 cumeecs) is only in the order of a "20-year flood." Mosul's good fortune in escaping major floods during the past 40 years should not lead to false hopes that such floods will not occur in the future.

Flood protection is generally provided against something less than the probable maximum flood; in doing so, a risk must be recognized that some day the protection will almost certainly be inadequate. The question is not whether the extremely large flood will occur; the question is when it will occur. It may occur in some year centuries from now; it also has an equal chance of occurring next year. To illustrate, in 2365 years of flood history on the Tiber River at Rome, the maximum was in the 2011th year; in 300 years of record of the Seine River in France, the maximum was in the ninth year. Iraq must not assume that the "500-year flood" will wait 500 years for its occurrence.

Criteria for Development of the Tigris River Basin

The ultimate plan for the Tigris River Basin will be a compromise between many conflicting interests and demands. The principal uses to which the existing and proposed systems of reservoirs can be put are:

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- a. Flood protection
- b. Irrigation
- c. Production of electric power
- d. Navigation
- e. Rice flooding.

There are an infinite number of compromises that can be made among these uses. In our studies we have considered that the primary purpose of development is to increase irrigation to the maximum and at the same time to provide a high degree of flood protection. Although studies were undertaken to find the effect on the irrigation yield of assuring certain minimum flows for power purposes, production of power has been considered basically as a by-product of irrigation and flood control. In the same way, navigation has been considered to be of minor importance unless it can be provided for by meeting irrigation requirements, while rice flooding has been considered to be an expedient interim use of water.

The greatest hazard from flooding exists at Baghdad, where overtopping of the bunds would flood the entire city, with catastrophic losses of life and property. Any evaluation of flood reductions at Baghdad would apply almost equally to the agricultural areas bordering the Tigris River. Flood hazards also exist at Mosul to a lesser degree. Therefore, we have taken flood reductions at Baghdad and Mosul as the two criteria to be used in evaluating alternative systems for flood control.

Our studies indicate that the maximum firm irrigation yield that can be developed by any system of reservoirs is 38.0 milliards of cubic meters per year, as compared with a 27-year (1929-1956) average combined flow of the Tigris and Diyala rivers of 43.6 milliards. Provision of additional storage would involve evaporation losses which exceed the increase due to flow regulation. Because of this decrease in incremental yield as the maximum potential is approached, it is rarely economical in any river system to develop the full potential. Very simple economic comparisons indicate that this is true in Iraq. Accordingly,

Director General of Irrigation

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we have somewhat arbitrarily set 32 milliards per year (approximately 85 percent of the maximum potential) as the firm irrigation yield which any ultimate development should be able to deliver.

The consultant's report on the Jazira Irrigation Project states that the project is feasible if a high level of dead storage (3 milliards content) is maintained in an Eski Mosul Reservoir to command the project. This contingent ability of Eski Mosul to serve the Jazira Project has been considered as a factor in evaluating alternative systems.

The irrigation deliveries we have considered are in northern and central Iraq. The interests of lower Iraq may be seriously affected by the degree and method of utilization of the Tigris water resources. Factors of importance in this connection include the salinity of river flows in lower Iraq, possible intrusion of sea water into the Shatt-el-Arab due to reduced flows, and the economic and social well-being of the inhabitants of the Hammar Lake area. Because of these factors we have considered the relative amounts of system spills from alternative reservoir systems to be of some importance.

The most important consideration in arriving at a plan of ultimate development is usually one of economics, that is, the relationship of project costs to project benefits. Such economic evaluations are outside the scope of our assignment, which was primarily hydrologic in nature. Nevertheless, the hydrologic consequences of reservoir operations have a direct effect on economic benefits; therefore, we were able to use the results of our hydrologic studies to reach qualitative conclusions on the relative economic benefits of alternative systems. Construction costs of many of the proposed projects have been estimated by other consultants, and we have used these costs in our evaluations to the extent they are known to us. Thus, we have considered benefit-cost relationships in a qualitative manner in our evaluations.

Conclusions Regarding Reservoir Systems

We conclude that the following alternative additions to the existing system of Dokan, Derbend-i-Khan, and Wadi Tharthar (for flood control) are the most promising for ultimate development:

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- a. A high Eski Mosul Reservoir (elevation 335)
- b. An intermediate-height Fatha Reservoir (elevation 172.5)
- c. A high Fatha Reservoir (elevation 178)
- d. A low Eski Mosul Reservoir (elevation 320) and a low Fatha Reservoir (elevation 165)
- e. A high Eski Mosul Reservoir (elevation 335) and a high Bekhme Reservoir (elevation 550)
- f. An intermediate Fatha Reservoir (elevation 172.5) and a high Bekhme Reservoir (elevation 550).

The above listing does not indicate an order of preference. A comparison of these alternatives is given in Exhibit B.

Also included in Exhibit B is an evaluation of the various possible alternatives for initial development that will fit into the selected ultimate schemes. This permits evaluations as to which initial stage is best for interim benefits. The evaluation of initial stages is important since the possibility always exists that the selected ultimate development may never be attained. Nevertheless, the initial stage that is selected should not preclude the later ultimate development.

Exhibit B indicates that the existing system will have a firm irrigation yield of about 23.1 milliards of cubic meters per year, or about 61 percent of the maximum potential of the Tigris River System. The ultimate plan should make much greater use of Iraq's resources.

Additional flood protection also is needed, since it is apparent from Exhibit B that the existing system provides a relatively low degree of protection. Our studies show that the 1954 flood would have been reduced by this system from 11,000 to 5,700 cumecs at Baghdad, with, of course, no reduction at Mosul. The 1954 flood peak was only about 35 percent of the probable maximum flood. With the existing system, a flood of 50 percent of the probable maximum flood would still cause a flood peak at Baghdad of 9000 cumecs, which is beyond the capacity of

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the river channel. The maximum discharge passed by the channel in 1954 was about 7000 cumecs; undoubtedly the channel will deteriorate and have a lower capacity with future diversion of normal floods at Samarra.

We have considered that the development of Wadi Tharthar for irrigation purposes is not advisable because (a) the project would not provide adequate flood control unless the existing diversion facilities were greatly expanded, (b) it would preclude the economic development of other reservoirs, at least one of which is needed for additional flood control if the diversion facilities are not expanded, (c) it would substantially increase system evaporation losses and thus reduce spills which would be of benefit to lower Iraq, (d) it would reduce the power potential at Samarra, and (e) it would involve excessively long hold-over storage, which raises doubts about initial filling, refilling after critical periods, and salinity of the stored water. We consider it very unlikely that any possible lower construction costs for the Wadi Tharthar Project, as compared with alternatives achieving the same firm irrigation yield and degree of flood control, would be sufficient to outweigh these disadvantages.

The most promising reservoir sites are limited to Eski Mosul, Fatha, and Bekhme. As an initial stage Bekhme offers less benefits for both flood control and irrigation, at probably higher cost, than either Fatha or Eski Mosul. Thus, the choice for initial development can be narrowed to Fatha and Eski Mosul. The selected criteria for ultimate development can be met by the full height of dam at either of these locations, by low dams at both Eski Mosul and Fatha, or by the addition of Bekhme to either of the two.

The justification for addition of Bekhme to either Eski Mosul or Fatha in the ultimate development is questionable. Bekhme adds very little benefit, at very high costs, when it is added to a high Fatha. When added to a high Eski Mosul, the benefits attributable to Bekhme are more significant, although it is doubtful whether the incremental benefits from Bekhme would justify its cost. Bekhme would be warranted in any ultimate scheme only if (a) power production became important, (b) large reservoirs were constructed in Turkey which would replace some of the regulation credited in our studies to Eski Mosul, or (c) it

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was considered imperative, in a system including Eski Mosul, to increase the firm irrigation yield above the 85 percent of maximum potential that is provided when the Jazira Unit is included. For these reasons we have retained the Bekhme Dam as an alternative, combined with dams at either Eski Mosul or Fatha.

In their ultimate stages a high Fatha Reservoir will develop more of the system potential than Eski Mosul (92.4 percent compared with 88.7 percent). This comparison is based on a low level of dead storage at Eski Mosul, which does not allow service to the Jazira Unit. In this manner, the yields of the two reservoirs are considered on a truly comparative basis, since Fatha, without Eski Mosul, also precludes service to the Jazira Project.

It is significant to note that the yield of Eski Mosul will be substantially reduced if service to the Jazira Project is provided by maintaining a high level of dead storage in the reservoir. For a high Eski Mosul, the firm irrigation yield will be reduced by 4.0 percent of the system potential, to 84.7 percent of the maximum attainable.

A choice between Fatha and Eski Mosul depends primarily upon (a) physical feasibility and cost of a dam at Fatha and (b) the desires of the Iraq Government for flood protection and irrigation development in the Mosul area, which are possible only with the Eski Mosul Reservoir. Neither of these is known to us at present.

If flood protection or irrigation development in the Mosul area is not desired, Fatha is the best choice for both initial and ultimate development, providing the cost per milliard of increase in irrigation yield would not be greatly in excess of that for Eski Mosul. Some excess in cost would be justified because Fatha gives additional flood-control benefits. An exact measure of such allowable excess in costs is difficult to state, but certainly costs per milliard of yield at Fatha that are 25 percent in excess of those at Eski Mosul would be very difficult to justify. If Fatha is built it might be economic to construct it in stages, with a low dam initially, to be raised later to its ultimate elevation. In that event, a less conservative provision for dead storage (as a sedimentation reserve) could be made for the initial stage. Accordingly, we have considered the low Fatha Dam with two levels of dead storage. The intermediate Fatha is also shown with two levels of dead storage, but in that case the level makes little difference to the firm irrigation

yield that is developed. However, we do not know whether stage construction of Fatha is technically feasible or economically desirable.

On the other hand, if (a) flood protection or irrigation in the Mosul area is considered important or (b) Fatha is considered physically infeasible or excessive in cost, then Eski Mosul is clearly the better choice. The consultant's report states that it could be constructed initially to its low elevation and later raised to its ultimate elevation, with only a minor penalty in additional capital cost because of stage construction.

A low Eski Mosul and a low Fatha may be worthy of consideration. Such a combination would increase the annual firm irrigation yield by about one milliard over a high Eski Mosul, as well as allow irrigation development of the Jazira Project. However, this combination would have about two milliards less firm irrigation yield than a high Fatha. The combination would give more positive flood control than a high Eski Mosul and would add the benefits of flood protection at Mosul to the protection of Baghdad that would be available from a high Fatha alone. Cost estimates for Fatha will be necessary to determine whether the incremental benefits are worth the high incremental costs that undoubtedly would be involved.

There is much to be said for the selection of a low Eski Mosul Dam as the initial stage of development. This would provide flood protection for Mosul and would offer considerable flexibility to meet future alternative plans. The low Eski Mosul can (a) allow later development of the Jazira Project, (b) be raised to its ultimate height to develop about 85 percent of the maximum potential of the basin, (c) be combined with a low Fatha, or (d) be combined with Bekhme if power is found to be important or dams are constructed on the Tigris in Turkey.

Power Production

The effects of maintaining various minimum flows for potential power installations at Samarra, Dokan, and Derbend-i-Khan are shown on Exhibit C. The results give an index of the minimum power that would result from operations giving absolute priority to irrigation, as compared with the minimum power that could be maintained if minor reductions in irrigation deliveries were permitted in favor of power production. The minimum power could be increased by from 50 to 100 percent,

Director General of Irrigation

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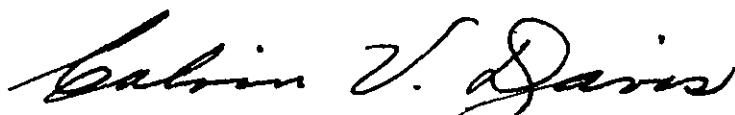
depending on the system adopted, by permitting reduction in irrigation deliveries of only three to four percent.

The large increase in benefits that can be obtained by such increase in firm power releases, at little sacrifice to irrigation, should merit serious consideration. A factor in such consideration is that the loss in firm irrigation yield is not a complete loss, as such losses will be recovered for beneficial use in lower Iraq.

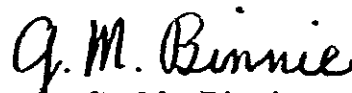
We have appreciated the opportunity to work on this important and most interesting assignment and would be pleased to answer any question that may arise concerning our investigations.

Respectfully submitted,

HARZA ENGINEERING COMPANY


Calvin V. Davis

BINNIE & PARTNERS


G. M. Binnie

SUMMARY OF OPERATION STUDIES OF MOST PROMISING RESERVOIR SYSTEMS

System Designation	System Additions to Daman, Darband-Khan, and Existing Wall Tharthar (milliards)	Total Dead Storage of System (milliards)	Flood Peak above Samarra Barrage			Flood Peak at Mosul			In flood protection provided to Mosul?	Annual System Firm Irrigation Yield			Can Jazira Irrigation Project be developed?	Minimum Flow at Samarra for Power (cusecs)	Approximate Construction Cost of Additional System 2/ (millions of ID)	Remarks	
			75%			50%				Total (milliards)	% of Basin Potential	Additional System (milliards)					
			Probable Maximum (cusecs)	75% Maximum (cusecs)	50% Probable Maximum (cusecs)	Probable Maximum (cusecs)	75% Maximum (cusecs)	50% Probable Maximum (cusecs)									
Natural flow with no reservoirs	0	-	37,000	27,800	18,500	30,000	22,500	15,000	No	17.3	45.5	-	No	150	-		
No additional reservoirs	-	-	35,700	23,600	15,800	30,000	22,500	15,000	No	23.1	60.8	-	No	236	-		
BENEFITS FROM ULTIMATE SYSTEMS																	
1	High Eski Mosul	$\begin{Bmatrix} 3.0 \\ 0.5 \end{Bmatrix}$	19.0 21.5	18,100 18,100	14,200 14,200	11,300 11,300	10,600 10,600	6,000 6,000	5,000 5,000	Yes Yes	32.2 33.7	84.7 88.7	9.1 10.6	Yes No	302 341	$\begin{Bmatrix} 52.1 \\ 52.1 \end{Bmatrix}$	Reasonable control of floods throughout system and good irrigation yield. With high dead storage allows Jazira Development.
2	Intermediate Fatha	$\begin{Bmatrix} 4.0 \\ 2.0 \end{Bmatrix}$	22.8 24.8	15,000 15,000	10,000 9,900	9,900 9,900	30,000 30,000	22,500 22,500	15,000 15,000	No No	34.3 34.7	90.3 91.3	11.2 11.6	No No	347 351	$\begin{Bmatrix} \text{Possibly higher than System 1} \\ \text{Possibly higher than System 1} \end{Bmatrix}$	Good control of floodplains and good irrigation yield. No control of Mosul floods and no Jazira Development.
3	High Fatha	4.0	24.9	15,000	10,000	9,600	30,000	22,500	15,000	No	35.1	92.4	12.0	No	355	Probably higher than System 1	Excellent control of floodplains and high irrigation yield. No control of Mosul floods and no Jazira Development.
4	Low Fatha and Low Fatha	$\begin{Bmatrix} 7.0 \\ 4.0 \end{Bmatrix}$	21.3 23.1	10,000 10,000	10,000 9,600	9,600 9,600	13,000 13,000	10,500 10,500	5,000 5,000	Yes Yes	32.9 33.9	86.5 89.2	9.8 10.8	Yes Yes	311 318	$\begin{Bmatrix} \text{Undoubtedly higher than System 1} \\ \text{Undoubtedly higher than System 1} \end{Bmatrix}$	Excellent control of floods throughout system and good irrigation yield. Eski Mosul high dead storage allows Jazira Development. Probably high cost.
5	High Eski Mosul and High Fatha	1.5	26.8	15,800	12,400	9,700	10,600	6,000	5,000	Yes	35.2	92.6	12.1	Yes	331	90.9	Adds comparatively small increment to benefits obtained from Fatha. Mosul alone is likewise worthy of consideration only if power becomes important or if dams are built in Turkey.
6	Intermediate Fatha and High Fatha	4.5	30.4	10,000	10,000	9,600	30,000	22,500	15,000	No	35.6	93.7	12.5	No	363	Undoubtedly high	Adds comparatively small benefits to Intermediate Fatha alone. Addition of Fatha is worthy of consideration only if power becomes important.

INTERIM BENEFITS FROM ALTERNATIVE STAGES OF ABOVE ULTIMATE SYSTEMS

System Designation	System Additions to Golan, Daboudi-Khan, and Existing Dead Storage (millions of cu m)	System Active Storage (millions of cu m)	Flood Peak at Mosul			Is flood protection provided to Mosul?	Annual System Firm Irrigation Yield			Can Jazira Irrigation Project be developed?	Minimum Flow at Samarra for Power (cusecs)	Approximate Construction Cost of Additional System ² (millions of ID)	Remarks
			Probable Maximum (cusecs)	75% Maximum (cusecs)	50% Probable Maximum (cusecs)		Probable Maximum (cusecs)	75% Maximum (cusecs)	50% Probable Maximum (cusecs)				
			Probable Maximum (cusecs)	75% Maximum (cusecs)	50% Probable Maximum (cusecs)		Probable Maximum (cusecs)	75% Maximum (cusecs)	50% Probable Maximum (cusecs)				
A	Low Fatha, as initial stage of System 1, 4, or 5	13.5	19,200	14,400	10,900	Yes	12,900	10,500	5,000	Yes	267	45.6 ⁴	Lowest cost, substantial benefits throughout system, flexible in fitting alternative future plans.
B	High Fatha, as initial stage of System 5	16.6	29,000	16,600	12,900	No	30,000	22,500	15,000	No	313	38.8 ⁴	Much less general benefit than Alternative A, without significantly lower cost.
C	Low Fatha, as initial stage of System 2, 3, 4, or 5	16.6	18,000	10,000	9,900	No	30,000	22,500	15,000	No	307	Not known	Less general benefit than Alternative A, at probably higher cost.

Reservoir Description

Reservoir	Normal Maximum Reservoir Elevation
Low Eski Mosul	120
High Eski Mosul	135
High Fatha	550
Low Fatha	165
Intermediate Fatha	175
High Fatha	178

¹ Where two values are shown, those represent alternatives of dead storage.

² Not including cost of power facilities or purchase of lands and damages.

³ 1960 cost estimate.

⁴ 1953 cost estimate of Fatha of ID 16, 185, 000, adjusted to 1960 by 11%.

Source: U.S. Army Corps of Engineers.

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SUMMARY OF FLOOD STUDIES

Sub-Dasin	Effective Drainage Area (sq. Km.)	Maximum Recorded Flood			Date	Maximum 20-Day Volume (milliards)	Probable Maximum Flood		
		Maximum Daily Average Discharge (cumecs)	Peak Discharge (cumecs)	Maximum Daily Average Discharge (cumecs)			Maximum Daily Average Discharge (cumecs)	Peak Discharge (cumecs)	20-Day Volume (milliards)
Tigris River above Eski Mosul Dam site	50,200	5,770 ^{1/}	-	-	17/2/35	6.6 ^{1/}	29,000	30,000	13.5
Greater Zab River above Bekhme Dam site	16,600	6,850	8,700	-	10/2/41	3.5 ^{2/}	20,500	23,000	8.4
Lesser Zab River above Dokan Dam	11,700	3,440	3,660	-	25/3/54	2.7	15,000	18,000	4.3
Tigris River above Samarra and below Eski Mosul, Bekhme, and Dokan	30,800	-	-	-	-	-	-	11,000	-
Tigris River above Samarra	109,300	12,400	-	-	26/3/54	13.0	36,000	37,000	22.7
Tigris River above Diyala-Tigris confluence and below Samarra Barrage	13,800	2,110 ^{3/}	2,900 ^{3/}	-	27/12/52	0.6 ^{3/}	12,000	13,000	-
Tigris River above Baghdad	123,100	12,000 ^{4/}	-	-	12/2/41	-	33,000	34,000	-
Diyala River above Derbend-i-Khan Dam	17,800	3,340 ^{5/}	-	-	25/3/54	2.6 ^{5/}	21,500	25,000	7.5
Diyala River above Diyala Weir and below Derbend-i-Khan Dam	11,900		-	-	-	-		11,000	-
Tigris River at Diyala-Tigris confluence	152,800	-	-	-	-	-	35,000	36,000	-

^{1/} At Mosul ^{3/} At Injana on Adhaim River ^{5/} At Diyala Weir
^{2/} At Eski Kelek ^{4/} Estimated

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System Location	Total System Additions to Tanks, Dams, Reservoirs, and Existing Wild Thickets (milliards)	Flood Peak				Flood Peak in Mosul				In flood protection provided to Mosul?	Annual System Firm Irrigation Yield				Can Irrigation Project be developed?	Minimum Flow at Samarra (cunecs)	Approximate Cost of Additional System (millions of ID)	Remarks
		Below Samarra Dam		75%		75%		50%			Total		% of Basin Potential					
		Probable Maximum (cunecs)	Probable Minimum (cunecs)	Probable Maximum (cunecs)	Probable Minimum (cunecs)	Probable Maximum (cunecs)	Probable Minimum (cunecs)	Probable Maximum (cunecs)	Probable Minimum (cunecs)		Probable Maximum (milliards)	Probable Minimum (milliards)	Total (milliards)	% of Basin Potential				
1	High Euphrates	18,100	14,200	11,300	8,600	5,000	Yes	32.2	84.7	9.1	Yes	302	52.1	Responsible control of floods throughout system and good irrigation yield. With high dead storage allows Jazira Development				
2	Intermediate Euphrates	18,100	14,200	11,300	8,600	5,000	Yes	33.7	86.7	10.6	No	341						
3	High Euphrates	18,100	14,200	11,300	8,600	5,000	No	34.3	90.3	11.2	No	347		Good control of Baghdad floods and good irrigation yield. No control of Mosul floods and no Jazira Development.				
4	Low Euphrates and Taw Euphrates	18,100	14,200	11,300	8,600	5,000	No	34.7	91.3	11.6	No	351						
5	High Euphrates and High Tigris	18,100	14,200	11,300	8,600	5,000	No	35.1	92.4	12.0	No	355		Excellent control of Baghdad floods and high irrigation yield. No control of Mosul floods and no Jazira Development				
6	Intermediate Euphrates	18,100	14,200	11,300	8,600	5,000	Yes	32.9	86.5	9.8	Yes	311		Excellent control of floods throughout system and good irrigation yield. With High Euphrates dead storage allows Jazira Development. Probably high cost.				
7	High Euphrates and High Tigris	18,100	14,200	11,300	8,600	5,000	Yes	33.9	87.2	10.8	Yes	318						
8	High Euphrates and High Tigris	18,100	14,200	11,300	8,600	5,000	Yes	35.2	92.6	12.1	Yes	331	90.9	Adds comparatively small increase to benefits obtained from Euphrates alone. Backing worthy of consideration only if power becomes important or if dams are built in Turkey.				
9	Intermediate Euphrates	18,100	14,200	11,300	8,600	5,000	No	35.6	91.7	12.5	No	363		Adds comparatively small benefits to Intermediate Euphrates alone. Addition of Tigris worthy of consideration only if power becomes important.				

TRANSFORM BENEFITS FROM ALTERNATIVE STAGES OF ABOVE-GROUND SYSTEMS

	A	B	C
Low Peak Month, as initial stage of System 1, 2, or 3	11.5 16.0	14.6	16.6
High Peak Month, as initial stage of System 1, 2, or 3	19,200 17,200	29,000	38,000 18,000
Low Peak Month, as initial stage of System 2, 3	14,400 14,400	12,000	10,000 10,000
High Peak Month, as initial stage of System 2, 3	10,000 10,000	22,400	22,400 22,400
Yes	5,000 5,000	No	No
Yes	28.9 10.4	31.6	10.3 11.3
Yes	75.0 80.0	81.6	79.7 82.4
Yes	9.4 7.4	7.9	7.2 8.2
Yes	267 108	No	No
Yes	45.6 3.7	33.3	Not known
Lower cost, substantial benefits throughout system, flexible to follow alternative future plans.		Much less general benefit than Alternative A ₁ , without significantly lower cost.	Less general benefit than Alternative A ₁ , at probably higher cost.

THEORY OF THE

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[illegible][illegible][illegible]

1. $\lim_{n \rightarrow \infty} \frac{1}{n} \sum_{k=1}^n \log \left(\frac{1}{1 - \frac{1}{k}} \right) = 1$

13

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**EFFECT OF MAINTAINING MINIMUM POWER FLOWS
ON FIRM IRRIGATION YIELD**

System Additions to Dokan, Derbend-i-Khan, and Existing Wadi Tharthar	Dead Storage of System Additions ² (milliards M ³)	Location of Power Installation	Minimum Flow Without Regard to Power (cunecs)	Minimum Flow Maintained for Power (cunecs)	Annual Firm Irrigation Yield	
					Without Flow Maintained for Power (milliards M ³)	Percent Reduction With Flow Maintained for Power
Natural flow with no reservoirs		-	150	-	17.5	
No additional reservoirs						
		Samarra	236	400	23.1	3.7
		Dokan	-	110	23.1	4.1
		Derbend-i-Khan	-	75	23.1	0.4
Low Eski Mosul	3.0	Samarra	267	500	28.5	6.0
Low Eski Mosul	0.5	Samarra	307	500	30.4	5.1
High Eski Mosul	3.0	Samarra	302	500	32.2	5.0
High Eski Mosul	0.5	Samarra	341	500	33.7	1.4
High Bekhme	0.5	Samarra	313	500	31.0	4.5
Low Fatha	4.0	Samarra	307	500	30.3	5.1
Intermediate Fatha	4.0	Samarra	347	500	34.3	1.2
High Fatha	4.0	Samarra	355	500	35.1	1.3
Low Eski Mosul and Low Fatha	7.0	Samarra	311	500	32.9	1.0
High Eski Mosul and High Bekhme	3.5	Samarra	331	500	35.2	1.8
Intermediate Fatha and High Bekhme	4.5	Samarra	363	500	35.6	0.7

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CHAPTER I

EXPANSION AND OPERATION OF THE
HYDROLOGIC NETWORK

Summary

Network Installations

Network Operations

Chapter 1

EXPANSION AND OPERATION OF THE HYDROLOGIC NETWORK

Summary

1.1 Iraq has made considerable progress during the last 30 years in evaluating its water resources. The general magnitude and distribution of these resources were indicated by the network of stream-gaging stations existing in Iraq before the start of the Hydrological Survey in 1956. However, this network was insufficient to provide all the detailed information required by the Government of Iraq for the future management of the country's water resources and for the optimum operation of its system of reservoirs. A study was therefore made of the required expansion and development of the hydrologic network. This study was documented in a letter-report entitled "Preliminary Needs for Hydrologic Data," dated 1 July 1956, which was used as a basis for the later development of the network in Iraq. This network is considered adequate to meet most of the needs for hydrologic data for some time to come.

1.2 The 1956 report was also used for international negotiations with Turkey and Iran for the proposed expansion of the network into the Tigris and Euphrates drainage basins in those countries. Agreement at the engineering level, covering the proposed installation and operation of rain gages, stream-gaging stations, and snow-survey courses, was reached with the Turkish Government authorities at a meeting in Ankara, 22-24 October 1956, which was also attended by representatives of the Irrigation Directorate and which was fully covered by our letter-report following the meeting. However, as far as we are aware, little if any expansion of

hydrological work in Turkey to meet the needs of Iraq has actually taken place. Only preliminary informal discussions at the engineering level were held with Iran. We consider it very important for Iraq to have hydrological data from Turkey and Iran, where much of the water of the Tigris and Euphrates basins originates. We strongly recommend that international negotiations be resumed at the earliest practicable date.

1.3 The hydrological network in Iraq consists of three component groups of installations: stream-gaging and sediment-sampling stations, snow-survey courses, and meteorological stations. These component networks, including the developments already carried out in Iraq, are shown on Exhibits 1, 2, and 3. (Exhibit 3 also shows proposed expansions into Turkey and Iran.) Photographs of typical installations are shown on Exhibit 4. The installations are described in detail in Appendix A.

1.4 A complete supply of modern stream-gaging and meteorological equipment, together with adequate spares, was procured and installed in Iraq. Automatic recording precipitation gages for the extension of the meteorological network into Turkey and Iran were also procured and have been handed over to the Irrigation Directorate.

Network Installations

Stream-Gaging Installations

1.5 The extension and improvement to the stream-gaging network that we have planned and executed is geared to the proposed development program in Iraq. The network we found existing provided reasonably reliable records as far back as 1930 and was most useful in planning

further stream gaging. However, several gages were in need of improvement, and additional gages were needed for future planning and operational purposes.

1.6 The purpose of the stream-gaging program can best be demonstrated by reference to Exhibit 1. The new station at Tusan is intended to furnish data for operation of the projected Eski Mosul Reservoir and for possible future international discussion on the available waters of the Tigris River. The new stations at Ifraz, Goma Zerdala, and Adhaim Narrows replace old stations nearby where the quality of measurements was inadequate because of the type and location of the previous gaging facilities. The new stations at Jindian and Balikian were installed in conjunction with increased meteorological and snow-survey installations in the Ruwanduz sub-basin so that a study can be made of the runoff from this comparatively small area; this region is of special interest in being typical of the mountainous districts of the Tigris Basin. The improvements noted for five stations are for the purpose of raising the standard of their data, since these stations are of particular importance in the planning and operation of river control.

1.7 Our plan for extension and improvement of the stream-gaging network was reviewed by the then Chief Hydraulic Engineer of the U. S. Geological Survey, who took leave from that organization while temporarily employed by us. He drew upon his 40 years of experience in stream-gaging programs in concurring with our proposals; he also reviewed and approved our methods of computing historical streamflows at 17 existing stations.

1.8 The stream-gaging installations involved by far the greatest amount of construction work of all the Hydrological Survey activities. The

work done included the construction of six new stations and major improvements to five existing stations, as shown on Exhibit 1. A description and sketch of each of these stations is given in Appendix A. The essential elements of stream-gaging stations are the facilities for obtaining (a) discharge measurements and (b) continuous records of gage heights.

1.9 For obtaining discharge measurements ten cableways were built or reconstructed to span the stream at the station. The cableways consist of a main cable carrying a travelling platform or car from which the discharge observer takes depth soundings and water velocity observations at many points across the river. The total river discharge is determined from these observations. The car is moved along the main cable by a traversing cable attached to a winch on the bank. Three cableways are Class I; at these the traversing winches can be operated by either hand or power and the cars can be raised or lowered from the main cable. These structures are also capable of transporting light motor vehicles. The other seven cableways are Class II; here the traversing winches are hand-operated only, and the cars remain at a fixed distance below the main cables. A boat is employed for low-flow measurements at Ifraz, and small rivers are measured at low flows by wading.

1.10 Ten gage wells were constructed, consisting of vertical wells connected to the river by steel intake pipes so that the water level in the well is the same as that in the river. A float in the well operates an automatic water-level recorder housed on top of the well, thereby giving a continuous record of the river gage height. The gage well usually consists of an excavated section in the river bank lined with corrugated steel pipe sections or brick masonry and backfilled with concrete and a tower section usually of concrete block construction extending above the highest water level expected. The entire well is in excavation at three stations, and at

one station the tower part of the gage well consists of corrugated steel pipe supported by a bridge pier. Concrete block towers are up to three meters square, and corrugated pipe is about 1.2 meters in diameter. The overall height of the structures is generally from ten to fifteen meters.

1.11 The water-level recorders are instruments that make a trace of gage height on a continuously moving chart, thereby providing a record of every fluctuation in the stream. They operate automatically for long periods of time and require only occasional attention.

Sediment-Sampling Network

1.12 River control in Iraq, both existing and planned, will change the amount and characteristics of river sediment and also change the capacity of the rivers to carry the sediment. Evaluation of these changes is very necessary and requires data on sediment carried by the rivers both before and after control is effected. Data on sediment are also essential in planning any channel improvements.

1.13 All the rivers of Iraq carry substantial quantities of suspended sediment, the amount varying greatly both in time and location. Huge amounts of sediment enter the river channels during periods of heavy runoff from denuded lands and to a lesser extent from all other lands. The ability of the river to transport this sediment depends on many hydraulic factors and varies both in time and location, so that the rivers are sometimes depositing sediment in their channels and at other times are picking up sediment and transporting it farther downstream. These two processes tend to be in rough equilibrium for rivers in their natural state, but any changes in river regimen, such as construction of reservoirs and diversion channels, has a marked and sometimes unpredictable effect on sediment transportation.

1.14 A reservoir retains the greater part of any entering sediment, and the water released is relatively clear. This released flow tends to acquire a sediment load appropriate to its regimen, by picking up sediment from the channel downstream of the reservoir and thus making a gradual enlargement of the channel in that reach. On the other hand, reduction of floods resulting from construction of the reservoir (or the diversion of flood waters) reduces the maximum ability of the river to transport sediment. Any sediment entering the river from tributaries downstream of the reservoir will not be transported as formerly, causing an accumulation in the river channel below the tributaries. Thus the main channel tends to be lowered and enlarged immediately downstream from the reservoir but raised and diminished still farther downstream wherever tributaries contribute sediment. The lengths or reaches of river in which these effects will be significant cannot be determined accurately before construction of the reservoir or flood-diversion channel.

1.15 There is good reason to believe that the channel of the Tigris River above and below Baghdad will deteriorate as a result of the diverting of high floods to Wadi Tharthar since 1956, and it is imperative that detailed records be kept of the channel capacity so that remedial measures can be taken before the situation becomes critical. A good overall check on the situation for the vicinity of Baghdad can be obtained by observation of the rating curve for the Serai gage. The rating for this station shifts continually, but we have been unable to detect any general trend in the 28 years of record. If in the future it should be found that gage heights for the same discharge are definitely higher, this is a warning that the channel is deteriorating with a consequent increase in flood danger.

1.16 Any remedial action will require reliable data on sediment transported by the Tigris. To provide such data and also to give an

indication of the useful life of reservoirs, we established sediment-sampling stations at six stream-gaging stations, with samples being taken on a regular routine. The locations of the stations are shown on Exhibit 1. Additional intermittent samples were taken on the Balikian and Ruwanduz rivers and below Dokan Dam on the Lesser Zab River.

1.17 Sediment samplers of two of the latest types and additional equipment for laboratory analysis were purchased for use by the Hydrological Survey. The samplers and procedures for field observations and laboratory analysis are described in Appendix A. All the sediment samples were taken at stream-gaging stations so no additional facilities, other than the sampling and analysis equipment, were required.

Snow-Survey Installations

1.18 There were no surveys of snow accumulation in the mountain headwaters of Iraq's rivers prior to the formation of the Hydrological Survey. Such observations will be vital to the streamflow forecasts that will be required for efficient operation of the reservoir system.

1.19 The object of measuring snow accumulation is to obtain an index of water stored in solid form in the basin. When sufficient years of record become available, these indices may be correlated with summer runoff considered to have been produced by the melting of the sampled snow and ice cover, and thus they make possible the forecasting of summer runoff from snow data collected in early spring. With such forecasts, greater than normal evacuation of reservoir space can be made in years of expected heavy runoff to provide additional storage for flood-control purposes. Conversely, smaller than normal evacuation can be made in dry years to minimize the chance of wasting irrigation water by flood-control operations.

However, it should be emphasized that snow surveys are intended to serve only as an index and must not be expected to provide a quantitative estimate of the average depth of snow water over a particular basin.

1.20 The snow-survey program of the Hydrological Survey was formulated by the engineer in charge of the large network of snow surveys in the United States. He spent two months in Iraq as our temporary employee, during which time he selected sites for many of the snow courses and gave intensive training to other engineers.

1.21 A snow course is a location where the depth and water equivalent of the snow are measured. It usually consists of two to four lines having a total of 10 to 20 sampling points, located at intervals of several meters. The lines are carefully marked at each end and at turns with brightly painted steel poles extending above the greatest depth of snow ever expected. A core sample of the snow is taken at each sampling point with a specially constructed hollow aluminum tube. The depth of the snow is noted, and the tube and sample are weighed with special scales calibrated to read directly the depth of water that would result if the snow were melted (referred to as the "water equivalent" of the snow). Snow courses are carefully selected to minimize the effects of drifting and exposure; the averaging of depths and water equivalents at the points of the course tends to reduce any such effects remaining.

1.22 A complete network of 23 snow courses was established in the mountainous districts of Iraq. Thirteen of the courses were established for the initiation of measurements in 1957, with the additional courses being established in 1958 and 1959. The locations of these 23 snow courses are shown on Exhibit 2. Procedures for establishment and operation of snow surveys, together with detailed descriptions of individual courses, are given in Appendix A.

1.23 Approximately 20 to 25 snow courses are proposed for the Tigris and Euphrates basins in Turkey and from eight to ten for the Tigris Basin in Iran. The installation of these snow courses is dependent upon the consummation of international agreements, for which early resumption of negotiations is strongly recommended. No selections were made for sites for snow courses in Turkey and Iran since a careful field reconnaissance must precede such a selection. The selection of sites should be made by an engineer with considerable experience in this work.

1.24 The network we have established in Iraq will allow good forecasting of seasonal inflows to Dokan Reservoir after a minimum of ten years of data has been obtained for correlation purposes. The network should be fairly good for forecasting seasonal inflows to Derbend-i-Khan Reservoir. However, the installations proposed in Iran would be very helpful in improving forecasting for both reservoirs. The installations proposed in Turkey are essential for the development of accurate forecasting and river-control procedure for the remainder of the Upper Tigris Basin, for which the existing network is inadequate.

1.25 The snow survey work was initiated with British personnel, since no snow surveys of any kind had previously been made in Iraq and the techniques of working under arduous snow conditions had to be taught as well as the techniques of snow surveying itself. Recruitment of suitable Iraqi personnel proved difficult. The right combination of integrity, physical endurance, intelligence, and, above all, enthusiasm for the work had to be found among such inhabitants in the neighborhood of the snow courses as were free to be engaged. It was essential that recruits should be local inhabitants so as to maintain continuity and to facilitate turning over the snow survey work later to the Iraq Government. By May 1959, when the Hydrological

Survey closed down its field work, several Iraqi snow surveyors had been trained, but higher supervision and direction is essential. The whole problem is discussed in detail in Appendix A.

Meteorological Installations

1.26 The network of precipitation stations previously existing in Iraq was inadequate to give a reasonable sample of rainfall over the various river basins of northern Iraq. Furthermore, there was very little information on intensities of rainfall or on evaporation. One of the major tasks of the Hydrological Survey was therefore to strengthen the network, with special emphasis on areas contributing substantial runoff. The expansion consisted of establishing 17 non-automatic rain gages, 15 automatic recording rain gages, three evaporation stations, and one temperature-recording station. The new stations are shown on Exhibit 3, which also shows the approximate locations of the precipitation gages proposed to be installed in Turkey.

1.27 The approximate locations for the new precipitation gages in Iraq were selected on a map in order to give good areal coverage. The final locations of most of the stations were determined in the field by a meteorologist on loan from the British Meteorological Office and in our temporary employ. The factors influencing final site selections and details of the various installations are given in Appendix A.

1.28 The non-automatic gages are after the pattern of the standard rain gage of the U. S. Weather Bureau and were all manufactured in Baghdad. The automatic recording rain gages selected for use are of the weighing type graduated to give a cumulative record in millimeters of precipitation for a period up to eight days on each chart. This instrument is the type most widely used in the United States. A non-automatic gage was installed

alongside each automatic recording gage to provide a check on both the gage and the attendant. Operation of the installations has been satisfactory.

1.29 The evaporation stations were established to measure the evaporation losses that will occur from the surfaces of the reservoirs existing or proposed for Iraq. Evaporation does not vary from place to place as much as do most hydrologic phenomena. It was therefore deemed sufficient to establish three evaporation stations in northern Iraq which, along with similar stations established by other consultants elsewhere in Iraq, give a coverage sufficient for the purpose.

1.30 The instrumentation of the evaporation stations was planned to measure not only the evaporation but several of the factors that influence it, such as air temperature, wind movement, and humidity. The standard equipment of a station of the U. S. Weather Bureau was employed, including a Class A evaporation pan, an anemometer, automatic and non-automatic rain gages, maximum and minimum thermometers, and a sling type psychrometer. Details of installations are given in Appendix A.

1.31 Two evaporation stations were equipped with pyrhemometers that give a continuous record on a weekly chart of the heat energy received from the sun. The temperature-recording station contains a thermograph giving a continuous record of air temperature on a weekly chart. The pyrhemometer and thermograph records provide basic meteorological data which were not previously available and which will be useful in any future investigations of evaporation and of snowmelt in connection with flood studies and runoff forecasting.

Network Operations

Standards and Procedures

1.32 The field installations and their operation are based on standards used in the United States and modified where necessary to fit conditions in Iraq. General agreement was reached with the Irrigation Directorate and Meteorological Service of the Iraq Government on equipment and standards of observation and on field observers. Considerable effort was spent in preparing and distributing detailed instructions for the guidance of field observers on the standards to be followed in river-discharge measurements, sediment sampling, snow surveying, rain-gage observations, and evaporation observations. This sort of information is included in Appendix A.

Field Organization, Training, and Observation Programs

1.33 Our field program for the expansion and operation of the hydrologic networks was carried out under a senior field engineer with headquarters in Kirkuk. British engineers directed most of the construction work and provided the initial close supervision of the observations, being replaced with Iraqi personnel as soon as possible.

1.34 The training of discharge observers was given great attention. Engineers experienced in discharge measurements gave field instruction to groups and individuals; classroom instruction was also organized. Several of the observers had had initial training from the Irrigation Department, but many received all their training from the Hydrological Survey. The observers at all other types of hydrological stations established were recruited locally and given individual instruction at the site by our engineers.

1.35 The most difficult problem in the field training and observation program was the matter of salaries for Iraqi personnel. Arrangements were made with the government agencies to assign the reading of meteorological gages as collateral duty to government employees residing or working near the gages, so that changes of personnel would be a minimum when the government assumed full responsibility for the operation of the program. Where this was not possible, every effort was made to recruit at salaries that would fit into the government pay scale so as to permit continuity of personnel. Where no comparable work was already being carried out in Iraq, such as that of the snow surveyors, salaries were fixed at rates considered to be fair to both the government and the employees.

1.36 The personal relationship between observers and their supervisors was found to be a most important item in securing satisfactory performance from the field personnel. We strongly recommend that future supervisors keep in close touch with all observers to give them encouragement and a sense of the importance of their work, as well as to maintain adequate standards.

CHAPTER II

PROCESSING OF HYDROLOGICAL DATA

Summary

Collection and Processing

Chapter 2

PROCESSING OF HYDROLOGICAL DATA

Summary

2.1 Processing of hydrological data consists of checking the basic field measurements and computing results that are readily usable for planning and operational purposes.

2.2 The processing of data constituted a major activity of the Hydrological Survey of Iraq throughout its entire program. Much previously collected data were processed, especially streamflows; in many cases previous computations were reworked. Practically all field data collected by the Hydrological Survey itself were processed as they came into the office.

2.3 Our initial task was to make an inventory of the hydrological data that had been obtained in the past, mostly by Iraq Government departments. These data consisted of records of river gage heights, discharge observations, previously computed river discharges, and records of precipitation. The inventory was completed in 1956, and a program of systematic tabulation of all data and recomputation of data where necessary was developed at that time. Tabulation of daily and monthly precipitation data for Iraq was carried on simultaneously with the recomputation of previously computed streamflow data. A later phase of the work included tabulation of streamflow and precipitation data for the Tigris and Euphrates basins in Turkey.

2.4 The Hydrological Survey greatly expanded the data-collection networks and processed the data obtained until operation of the networks was turned over to the Iraq Government. Details of the expanded networks

are given in Chapter 1 and Appendix A, which also explains the procedures for processing the data. Data collected and processed included stream-flow, sediment concentration, snow depth and density, precipitation, evaporation, hourly temperatures, and solar energy. Processing was done under the direct supervision of American and British engineers with many years of experience in this type of work. Thorough training in data processing was thereby given to our Iraqi staff.

2.5 The processing of hydrological data will be a continuing activity of the Iraq Government, particularly the Irrigation Directorate, in the future. We emphasize the great importance of this work and the fact that, in order to obtain the most reliable results, processing should not be allowed to fall behind.

Collection and Processing

Previous Data

2.6 A large amount of previously collected streamflow data was tabulated and processed by the Hydrological Survey, as shown on Exhibit 5. A total of 562 station-years (a station-year is one station record for one year) of gage-height data were tabulated, and 253 station-years of discharge were computed for 26 of the more important gaging stations in Iraq. In addition, 646 station-years of gage-height record at 38 less important stations were recorded on microfilm. All these data were for non-automatic gages. In general, discharges were computed only for periods during which the gage-height record was considered satisfactory and also during which sufficient discharge measurements had been made by reasonably satisfactory methods to give a fairly reliable indication of any changing

relationship between gage height and discharge. The most important exception was Fatha gaging station, which is discussed in paragraphs 2.11 and 2.12.

2.7 Discharge computations made previously by the Irrigation Development (Haigh) Commission, the Irrigation Directorate, and various consultants were reviewed thoroughly. These earlier computations were made for varying purposes and consequently to different standards and with different degrees of thoroughness. We adopted these computations wherever it was considered that more intensive analyses would not materially increase their accuracy, but we recomputed where appropriate.

2.8 Previous computations had practically all been made on the basis of five-day mean gage heights. We considered this insufficiently accurate for most river conditions in Iraq and computed all flows on a daily basis except during periods of low flow at some stations. The methods of computation were substantially those used by the United States Geological Survey.

2.9 The river discharge standards adopted were also those of the U.S. Geological Survey. Computed daily discharges were judged to be "excellent" if, in general, the discharges were believed to be subject to errors of less than five percent; "good" if less than ten percent; "fair" if less than fifteen percent; and "poor" if more than fifteen percent. The annual and monthly discharges can be expected to be substantially more reliable than the general level of daily discharges because of compensating errors in the daily discharges.

2.10 The results of the streamflow computations for previously collected data were published in a report entitled "Discharges for Selected Gaging Stations in Iraq, 1930-1956," dated May 1958. The report also

gives descriptions and analyses of the gaging stations, together with our assessments of the standard of data for each station. We believe the report to be as accurate a compilation as can reasonably be made, but its accuracy depends mostly upon the reliability of the field measurements. Obvious errors in these recorded measurements were adjusted, as described in the analysis of each station, but others undoubtedly remain.

2.11 At Fatha gaging station on the Tigris, discharge measurements were made regularly from 1932 through 1933 and intermittently until 1938, but these were not at high discharges because of lack of adequate facilities. No further measurements were made until 1956, when the Iraq Petroleum Company kindly put one of its cableways on the site at the disposal of the Hydrological Survey and we were able to make measurements at all river stages. Fortunately the gaging section appears stable, and there was little permanent "shift" between the 1932-38 measurements and those made since 1956. The gage height record, however, was missing or suspect for much of the period from 1934 through 1956, and a somewhat unsatisfactory correlation with gage heights at Baiji had to be made for many years. The procedures used in computing Fatha discharges are described in more detail in the report of May 1958.

2.12 We have drawn particular attention to the standard of the Fatha discharge data lest users of the 1958 report be inclined to give more credence to the Fatha data than is justifiable when computing historical Tigris water resources before any water was lost to breaches during high flood. We devoted a special effort to building up the Fatha historical discharge record for this very purpose, but in our studies of Tigris reservoir operations in Chapter 5 we have been cautious in utilizing it. We consider the record to be the best obtainable, and in general it does not conflict with

the data of the upstream gaging stations; nevertheless, we recognize its limitations.

2.13 Data for stream-gaging stations and precipitation stations in Turkey were microfilmed in Ankara in October 1956 by a Hydrological Survey engineer and later tabulated on standard forms in Baghdad. In all, 14 station-years of monthly streamflow data and 576 station-years of daily and monthly precipitation data were tabulated for the more recent years. Data published by the Turkish Government for earlier years were also obtained and were turned over to the Iraq Government.

2.14 Much of the previously collected precipitation data for Iraq was available only in the files of the Directorate of Meteorology at Baghdad Airport. The Hydrological Survey tabulated a total of 828 station-years of daily and monthly data, which were published in a report entitled "Summary of Monthly Precipitation at Stations in Iraq, 1887-1958," dated May 1959. The bulk of the data is for the period starting in 1935, with only a few records available for earlier periods. The report included some of the new data collected by the Hydrological Survey after 1956.

2.15 Several other agencies besides the Directorate of Meteorology collected precipitation data that were submitted to the Directorate and thus are included in our report. These agencies included Iraq Railways, the Irrigation Directorate, the Iraq Petroleum Company, headmasters of a number of schools, and personnel at army and police posts. These co-operative stations, especially those in the latter categories, were mostly operated on a voluntary basis, and many gaps appear in their records; nor were these stations subject to detailed and frequent inspections by the Directorate of Meteorology.

Current Data

2.16 The data from the many new hydrological stations of various types that we established were processed as they came in from the field. The results of the streamflow computations were published in a report entitled "Discharges for Selected Gaging Stations in Iraq for Water Years 1957 and 1958," dated May 1959. This report also includes our later streamflow computations for the gaging stations that had appeared in the 1958 report.

2.17 The data in the later report is generally of a higher quality than that in the first, partly because the standard of field measurement had improved as a result of more training and supervision of field observers and partly because the basic data were being processed very soon after field measurement so that any anomalies could be inquired into almost immediately. We refer again to this latter point in our recommendations as to processing of future data.

2.18 The stream-gaging stations established or improved by the Hydrological Survey have all been equipped with automatic gage-height recording instruments, with two exceptions as explained in Appendix A. The processing of records from these stations involves a careful analysis of the recorder charts to determine the true mean daily gage heights, unless the stage is changing rapidly through the 24 hours, in which case the full benefit of the automatic recorder is obtained by breaking down into shorter periods. The procedures to be used are explained in Appendix A.

2.19 The sediment samples collected by the Hydrological Survey were analyzed at the Irrigation Directorate laboratory to determine the concentration in parts per million by weight. Each sampling involved three or

more individual water samples, as explained in Appendix A, depending on river depths and type of sampler used. The concentration of sediment was determined for each individual water sample, and the concentrations of all samples for a single observation were averaged. The average concentration and streamflow were then utilized to compute the daily sediment load. The analysis procedure is explained in Appendix A. The data for all samples collected by the Hydrological Survey are presented in Annex A-2 of Appendix A.

2.20 The snow-survey data were computed and checked in the field, and the only processing required was to copy on office forms. The data observed in the field were the depth of snow and the weight of a core sample in terms of an equivalent depth of water. The latter divided by the depth gave the density. Snow depth and equivalent water content were recorded in inches rather than in metric units because the only equipment available was graduated in inches. The snow data collected by the Hydrological Survey are given in Annex A-4 of Appendix A.

2.21 About half of the precipitation stations established by the Hydrological Survey were equipped with non-automatic rain gages and the other half with both non-automatic gages and automatic recording rain gages. The analysis of the records of the precipitation stations with non-recording gages consisted first of inspection of the field data to detect errors of listing and then of tabulation of the daily and monthly precipitation on standard forms. The analysis of the records of stations containing both types of gages consisted of comparing and evaluating the records of each gage. The automatic record is used to check the non-automatic record and to provide data on the distribution and intensity of precipitation during the day. Total daily precipitation can be determined with greater accuracy

from the non-automatic record than from the automatic record, and unless the former is shown to be unreliable, it is used when tabulating the values of daily and monthly precipitation on standard forms. The charts of the automatic recorders were filed systematically for future use. The daily precipitation at stations established by the Hydrological Survey is shown in Annex A-9 of Appendix A. The values of monthly precipitation at these stations were published in the precipitation report mentioned earlier.

2.22 Daily evaporation from the pans installed by the Hydrological Survey was measured in the field, with certain adjustments being made in the office. Daily evaporation from a pan is affected considerably by changes in heat storage, and daily results from a pan are not considered a reliable guide to daily evaporation losses from a reservoir. However, over a period of time these effects tend to be compensating, and monthly pan evaporation, multiplied by a coefficient of 0.7, gives a useful indication of reservoir evaporation. The adjusted monthly pan evaporation data are given in Annex A-11 of Appendix A.

2.23 The hourly temperature data were read from the weekly charts of the thermographs. The values actually tabulated were the instantaneous temperatures at each two-hour interval throughout the day. These data are given in Annex A-10 of Appendix A.

2.24 The solar energy data from the automatic recording pyrheliometers established in the snow areas of northern Iraq have not been thoroughly analyzed. These data are for reference purposes in future, highly specialized studies of snowmelt influences at such time as a review is made of the flood studies in the light of additional data of several types.

Future Data

2.25 The processing of data for both the older and the recently established hydrological stations will continue to be a substantial task. We strongly recommend that processing be kept up-to-date as far as possible. Experience elsewhere, as well as our experience in Iraq, has clearly shown that far more reliable results can be obtained if basic data are fully recorded and computed as they come in from the field. Apparent inconsistencies in results can then be investigated while there is still first-hand knowledge of particular field conditions at the time of observation; errors in methods of measurement made by some observer can be discovered and corrected after not too long a period.

2.26 Processing of hydrologic data should be under the direct supervision of an experienced engineer, who should carefully review the final results. The Hydrological Survey gave thorough training in this work to several Iraqi engineers, who should form the nucleus of an expanded staff that will process all future data. In that way the Iraq Government will realize full benefits from the expanded hydrologic networks.

CHAPTER III
FLOOD STUDIES

Introduction
Flood History
Probable Maximum Flood
Flood Frequency
Flood Volumes

Chapter 3

FLOOD STUDIES

Introduction

3.1 The assignment of the Hydrological Survey of Iraq included a detailed analysis of the flood potential of the Tigris River Basin. Estimates of flood potential are essential for design of spillways for dams and for policy decisions by the Iraqi Government on the degree of flood protection to be afforded.

3.2 The probable maximum flood and the probabilities of historical floods have been computed for important locations in the Tigris River Basin. The limited flood history of the basin has been supplemented by the computation of probable maximum floods, based on an analysis of storm and snow-melt potential and basin characteristics. A detailed description of the analysis and computations upon which the flood results are based is presented in Appendix B of this report.

3.3 The computed probable maximum flood peaks are several times greater than the maximum recorded peaks. The history of Baghdad since its establishment in A.D. 762, however, includes reference to many floods, some of which according to descriptions must have been substantially larger than the greatest in the last fifty years.

3.4 Flood protection is generally provided against something less than a probable maximum flood, and the risk must be recognized that at some time the protection will be inadequate. The question is not whether the extremely large flood will occur; the question is "When will it occur?" It may occur hundreds or thousands of years from now, but it has an equal chance of occurring during the next flood season.

Flood History

Tigris River Basin

3.5 Gage height records in the Tigris River Basin date from 1906 at Baghdad, with reliable discharge measurements having been made only since about 1930. During this period the maximum flood experienced at Samarra was about 12,400 cumecs, in 1954. A flood of about 12,000 cumecs occurred in 1941. The maximum flows at Baghdad are difficult to estimate because of breaching of dikes, which allowed flow around Baghdad during the extreme flood periods. The maximum flow was probably that of 1941, when 12,000 cumecs was estimated as being the total flow, of which 8,100 cumecs was measured as being the flow in the main channel at Baghdad. The maximum total flow at Baghdad in the 1954 flood was probably slightly more than 11,000 cumecs, of which 7,100 cumecs was measured in the main channel.

3.6 Mr. Vahe Sevian, former Inspector General of Irrigation, Ministry of Agriculture, has compiled a list of floods that are reported to have occurred at Baghdad since the establishment of the city in the year A.D. 762. From that date until 1906, he records about 30 major floods in or around Baghdad. His tabulation was prepared from history books and religious records and gives qualitative reports of floods, rather than quantitative measurements of the maximum heights attained. While most of the serious floods in or around Baghdad are probably included in this listing, it is possible that some important floods were not noted in the historical documents.

3.7 The list shows Baghdad as having been flooded twelve times between A.D. 762 and 1906, with part of the city being destroyed on each

occasion. The flood waters entered Bamaristan Hospital through its windows on two occasions, in A. D. 1074 and 1174. Historical records indicate that this hospital was placed on one of the higher ground elevations west of the river; however, the exact elevation of the hospital is not known. The most serious flood is stated to be that of A. D. 1174, when the "Tigris River rose as it had never done before, with the whole of Baghdad being flooded and the water being so high that boats entered the Bamaristan Hospital through the empty doorways."

3.8 Quantitative estimates of the magnitude of discharges in the historical floods cannot be made. Therefore, this information cannot be used for a determination of the frequencies of large floods on the Tigris River. However, the flood history does support the conclusion that floods of considerably greater magnitude than have occurred during the 1906-1956 period have happened and can be expected to happen again.

3.9 Biblical history records the story of the flood experienced by Noah. This flood is thought to have centered its devastation on the ancient city of Ur on the Euphrates and is said to have lasted for 150 days. Stories of the flood may well have been exaggerated, and it may also have been accentuated by subsidence of the delta. However, the flood must have been of extreme magnitude to have various versions of its catastrophic results preserved by several ancient peoples.

Flood Experience on Other Rivers

3.10 The history of floods on other rivers throughout the world is filled with references to floods that were "higher than ever before," even in cases where river stages had been observed for centuries.^{1/} The time

^{1/} Hoyt and Langbein, Floods. Princeton University Press, 1955.

of occurrence of the greatest historical flood with respect to the total period of record also varies widely. Experience in other areas illustrates the fact that an extremely large flood can be imminent even though no large floods have occurred for many years. Reliable records for the Seine River in France date from 1649; the highest stage was 1658. On the Danube, records have been kept from the year 1000, with the highest stage in 1501 and the second highest in 1787. The first recorded flood on the Tiber River at Rome was in 413 B. C., but its maximum stage was not recorded until A. D. 1598. Even the Nile River, one of the most highly naturally regulated rivers in the world, has experienced "unusual" floods. In 747 B. C. the whole valley of the Nile is said to have turned into an ocean, and this occurred after seven years of extreme drought.

3.11 During the last century, flood data in the United States have been among the most detailed in the world. The experiences there are replete with instances of floods that were never believed possible by long-time residents of the areas involved. The Republican River at Bostwick, Nebraska (drainage area 52,000 square kilometers) reached a peak discharge in 1945 of 6700 cumecs, compared with a previous high of about 900 cumecs in 40 years of flood history. The Kansas River flood of 1951 reached a peak of 13,300 cumecs at Topeka (drainage area 147,000 square kilometers), compared with a previous high of 6200 cumecs in 100 years of flood history. The Connecticut River flood of 1936 was 8.6 feet higher than had been experienced in almost 300 years of habitation in the city of Hartford. Two years later a flood only 2.6 feet lower than the 1936 flood was experienced. The Ohio River at Louisville, Kentucky, was 10.4 feet higher in 1937 than it had been in the previous 105 years, with the peak discharge (31,500 cumecs) being about twice the previous record.

3.12 The above examples cannot, of course, be applied to the estimation of floods on the Tigris River, where the basin characteristics and climatic regimes are different. However, they do emphasize that it is extremely hazardous to base a prediction of the probable maximum flood peak solely on previous flood history. The entire range of conditions that affect flood peaks, including basin topography and shape, experienced storms, dewpoints, winds, snow accumulations, temperatures, and ability of the soil to absorb water, must be considered in the estimation of the probable maximum flood peak. This has been done in the analyses we have made.

Probable Maximum Flood

General Procedure

3.13 The probable maximum flood is the estimated flood that would result if all the factors which contribute to the generation of a flood were to reach their most critical values that could occur concurrently. The probable maximum flood is our estimate of the boundary between possible floods and impossible floods and as such has a chance of occurrence of zero or a return period of infinity.

3.14 Estimates of the probable maximum flood have been made for those sub-basins in the Tigris River Basin above dams, proposed damsites, and other important locations. The resulting flood hydrographs are shown on Exhibit 6, with pertinent data listed in Table 3-1. Similar estimates have not been made for the Euphrates River, although the basic preliminary work on the Tigris River would be to some extent usable for the Euphrates River.

Table 3-1

SUMMARY OF FLOOD STUDIES

Area Number	Sub-Basin	Effective Drainage Area (sq. km.)	Maximum Recorded Flood				Probable Maximum Flood			
			Maximum Daily Discharge (cumeecs)	Peak Discharge (cumeecs)	Date	Maximum 20-Day Volume (milliards)	Maximum Daily Average Discharge (cumeecs)	Peak Discharge (cumeecs)	20-Day Volume (milliards)	
4	Tigris River above Eski Mosul Dam site	50,200	5,770 ^{1/}	-	17/2/35	6.6 ^{1/}	29,000	30,000	13.5	
3	Greater Zab River above Bekhme Dam site	16,600	6,850	8,700	10/2/41	3.5 ^{2/}	20,500	23,000	8.4	
2	Lesser Zab River above Dokan Dam	11,700	3,440	3,660	25/3/54	2.7	15,000	18,000	4.3	
5	Tigris River above Samarra and below Eski Mosul, Bekhme, and Dokan	30,800	-	-	-	-	-	11,000	-	
2,3,4, & 5	Tigris River above Samarra	109,300	12,400	-	26/3/54	13.0	36,000	37,000	22.7	
6	Tigris River above Diyala-Tigris confluence and below Samarra Barrage	13,800	2,110 ^{3/}	2,900 ^{3/}	27/12/52	0.6 ^{3/}	12,000	13,000	-	
2,3,4,5, & 6	Tigris River above Baghdad	123,100	12,000 ^{4/}	-	12/2/41	-	33,000	34,000	-	
1	Diyala River above Derbend-i-Khan Dam	17,800	3,340 ^{5/}	-	25/3/54	2.6 ^{5/}	21,500	25,000	7.5	
7	Diyala River above Diyala Weir and below Derbend-i-Khan Dam	11,900	-	-	25/3/54	-	-	11,000	-	
1,2,3,4,5, 6, & 7	Tigris River at Diyala-Tigris confluence	152,800	-	-	-	-	35,000	36,000	-	
			3/ At Injana	on Adhaim River	5/ At Diyala Weir					
			2/ At Eski Kelek	4/ Estimated						

3.15 The probable maximum flood has two aspects, the flood peak and the flood volume. Both are of considerable importance, either for the determination of required spillway capacity or for estimates of the degree of flood control afforded by a reservoir. The probable maximum flood is due to runoff from a probable maximum rainstorm, preceded by runoff from a major storm, and combined with a high rate of snow runoff. The predominant contribution to the flood peak is the runoff from the very intense rainstorm. Whereas the snowmelt contribution to the peak discharge is relatively small, it represents a very large contribution to the flood volume. In our computations we have estimated the flood hydrograph for the maximum 20-day period.

3.16 The general procedure followed in estimation of the probable maximum flood is one that has gained wide acceptance in modern practice. A probable maximum storm was developed from a detailed study of historical storm occurrences, with the maximum historical storms being increased to their maximum potential by analysis of meteorological factors. The maximum snowmelt potential was also analyzed. The precipitation values of the probable maximum storm were reduced by estimated losses due to infiltration, interception, etc.; the residual values were applied to unit hydrographs developed for the relevant basin in order to arrive at the hydrograph for the probable maximum flood due to precipitation. To this was added the estimated maximum snowmelt runoff, to determine the total probable maximum flood.

3.17 A summary of the development of the 20-day flood is given in the following paragraphs. The procedure is described in detail in Appendix B.

Probable Maximum Precipitation

3.18 Probable maximum precipitation rates were determined for each sub-basin in the Tigris drainage area for a range of storm durations. Curves showing the relation of probable maximum depth of precipitation to area and time are presented on Exhibit 7 and summarized in Table 3-2. As indicated in Appendix B, the curves of Exhibit 7 cannot be used indiscriminately for all values of area and duration; proper use requires a special technique described in that appendix. The values indicated in Table 3-2 are correct for the basins indicated and correspond to the curves of Exhibit 7 for the areas shown.

3.19 Probable maximum precipitation over the drainage area of the Euphrates above Ramadi was estimated on the basis of Tigris Basin results. The Euphrates values, shown in Table 3-3, were not determined by as detailed procedures as the Tigris values and are considered to be less reliable.

3.20 Storms approach the Tigris Basin from the Mediterranean Sea as large counterclockwise-rotating air masses, roughly circular in plan. Due to the rotation of the air mass, the first rain-accompanied winds are usually southerly, giving rise to the popular lay opinion that the moisture source is the Arab Gulf.

3.21 Observed precipitation in 14 major historical storms was increased to the maximum potential for each sub-basin and for the Tigris River as a whole. This increase, called maximization, was based on maximum dewpoints and moisture-bearing winds observed in the general area. Six-hour precipitation increments were plotted for various areas covered by these maximized storms, and envelope curves were drawn to

Table 3-2

PROBABLE MAXIMUM PRECIPITATION, TIGRIS RIVER BASIN
(in millimeters)

Area Number	Sub-Basin	Total Area (sq. km.)	Duration (hours)							
			<u>6</u>	<u>12</u>	<u>18</u>	<u>24</u>	<u>36</u>	<u>48</u>	<u>72</u>	<u>96</u>
4	Tigris River above Eski Mosul damsite	50,200	60	112	142	167	205	236	267	289
3	Greater Zab River above Bekhme damsite	16,600	150	229	282	312	347	373	407	429
2	Lesser Zab River above Dokan Dam	11,700	170	253	316	346	384	411	439	464
5	Tigris River above Samarra and below Eski Mosul, Bekhme, and Dokan	33,900	43	71	92	108	138	156	174	187
2,3,4, & 5	Tigris River above Samarra	112,400	61	96	121	142	172	196	240	277
6	Tigris River above Diyala-Tigris confluence and below Samarra Barrage	22,300	70	113	132	159	192	216	243	264
2,3,4,5,&6	Tigris River above Baghdad	134,700	52	81	104	121	147	169	205	237
1	Diyala River above Derbend-i-Khan Dam	17,800	148	225	278	307	342	369	402	425
7	Diyala River above Diyala Weir and below Derbend-i-Khan Dam	11,900	113	165	192	215	250	275	313	336
1 & 7	Diyala River above Diyala Weir	29,700	114	150	175	190	214	232	264	290
1,2,3,4,5, 6, & 7	Tigris River at Diyala-Tigris confluence	164,400	50	85	106	120	141	162	198	232

produce curves of probable maximum depth versus area and duration. A map of mean annual precipitation over the Tigris Basin, produced as a step in the computation of maximum precipitation, is shown on Exhibit 8.

3.22 The hydrometeorological analysis indicated that the precipitation potential reaches two annual maxima, one about 15 November and one about 1 April. The annual variation in potential is shown on Exhibit 7. Maximum snow runoff can occur only in spring, and since the combination of maximum precipitation and snowmelt will give the maximum flood, the 1 April date was chosen for all flood computations.

Table 3-3

PROBABLE MAXIMUM PRECIPITATION,
EUPHRATES RIVER BASIN ABOVE RAMADI

Duration (hours)	6	12	18	24	36	48	72	96
Probable Maximum Precipitation (mm)	20	31	39	46	56	64	78	90

Retention Losses

3.23 Surface runoff or streamflow is equal to the volume of rainfall which remains after certain basin "losses" are satisfied. The losses to runoff from probable maximum rain, due to evapotranspiration, infiltration into the soil, and retention on the surface, were combined into one factor called retention loss. The retention loss was expressed as initial loss plus an hourly retention rate. The initial loss is a fixed quantity of rainfall which satisfies surface retention and initially high infiltration, while the uniform retention rate satisfies the equilibrium infiltration capacity of the soil and other losses during the storm. The estimated retention rates in the various sub-basins of the Tigris River Basin are shown on Exhibit 9.

3.24 Retention estimates were based on data from similar basins in the United States, supplemented by limited data from the analysis of floods and field inspections in the Tigris River Basin. In general, it was assumed that retention in the dry plains areas is very small because of the impervious nature of the soil. Retention in the foothills is believed to be moderate because of vegetation and the more organic character of the soil. Retention in the limestone mountain areas is estimated to be high because of the cavernous condition of the rock as indicated by the abundance of large springs. The retention losses used are believed to be the minimum that could be expected at the time of the probable maximum storm. We believe it very possible that the retention rate could be as much as one-third higher.

3.25 The values assigned as retention rates have an appreciable effect on the magnitude of probable maximum floods. Trial determinations using higher retention rates were made for the areas above Dokan and Eski Mosul. Our values of retention are believed to be conservatively low so that a decrease in the assumed values can hardly be expected. An increase of one-third in retention would result in reductions of about 22 percent in flood peak and 12 percent in 20-day volume for each area.

Unit Hydrographs

3.26 The effective storm precipitation (excess of precipitation over losses) was converted to river flow by use of unit hydrographs. A unit hydrograph is defined in these studies as the outflow from a basin caused by rainfall excess of one centimeter over the basin in six hours. The unit hydrograph theory is that for storms of similar duration and areal distribution over the basin, the time bases of the outflow hydrographs are equal

and the ordinates of the outflow hydrograph are directly proportional to the volume of rainfall excess. Thus a storm producing ten centimeters of rainfall excess in six hours would produce a hydrograph whose peak would be twice that produced by a storm with five centimeters of rainfall excess. The time required for surface runoff to be completed would be the same in each case.

3.27 Rainfall and river discharge data for the Tigris River system were not of sufficient detail for use in deriving unit hydrographs at each desired point. It was possible, however, to derive unit hydrographs for the Lesser Zab River at Dokan, the Khazir River at Manquba, and the Adhaim River at Injana, and these results were used as a key in developing synthetic hydrographs for the balance of the system.

3.28 A relation of unit hydrograph peak to drainage area was developed using the Tigris Basin unit hydrographs mentioned above and data from similar basins in the United States. Equations relating other unit hydrograph characteristics to basin shape, size, and topography were used to develop synthetic unit hydrographs for 14 Tigris River sub-basins. The relationships used, together with the resulting unit hydrographs, are shown on Exhibits 10a and 10b.

Snowmelt

3.29 An estimate was made of the snowmelt runoff which should be combined with probable maximum precipitation in the Tigris River Basin. No data on snow accumulation and snow water equivalent were available at the time the hydrometeorological studies were made, except for some daily snow depth records for a few low-altitude Turkish stations a short distance outside the Tigris Basin.

3.30 Mean winter precipitation for each sub-basin was converted to snow water equivalent on the basis of correlations developed from snow-survey, precipitation, and temperature data from 15 snow courses in Southern California, United States. Estimates of snow water equivalent and snowmelt volume are given on Exhibit 11.

3.31 The snow water equivalent was not maximized in the same sense as the probable maximum precipitation. The values represent a frequency of occurrence which, in our judgment, is in the order of once in 100 years. The difference in degree of possibility between probable maximum precipitation and the maximum snow accumulation does not introduce any variation in criteria. The flood crest resulting from a probable maximum storm will have receded long before all of the snow has been melted; therefore, the snow water equivalent must be only that necessary to ensure a supply of snow sufficient for several days of maximum melting rates prior to the maximum precipitation. The snow water equivalent values used are more than adequate for this purpose.

3.32 The snow water contribution to the peak flood period was estimated by assuming maximum historical temperature sequences. Snowmelt runoff was computed by the degree-day melt methods. Each degree-day (Fahrenheit) of melting temperature above the snowline was assumed to melt an equivalent of three millimeters of water over the portion of the basin covered with snow. It was further assumed that the runoff from each day's melt would be spread over 20 days.

Antecedent Flood

3.33 The meteorological analyses indicated that the probable maximum storm could occur four days after the occurrence of a storm of major proportions. The rain runoff from the flood of 1954 was assumed to be that

which would occur from such a major storm. The use of a major storm preceding the probable maximum storm requires that minimum retention rates be used at the time of the probable maximum storm and also that flood-control reservoirs be above rule curve level.

Probable Maximum Flood Peaks

3.34 The procedures outlined in the preceding paragraphs were followed for a number of maximized historical storms to determine the combination of maximized events that would give the highest flood peak for individual sub-basins. The results are given in Table 3-4. The maximum value determined from the various storms for each sub-basin was selected as the probable maximum flood peak, as indicated by "Adopted Value of Probable Maximum Flood," on Table 3-4. The equivalent Creager's "C" is shown for each adopted value.

3.35 The probable maximum floods at Samarra, Baghdad, and below the mouth of the Diyala River were determined by routing sub-basin floods. Several historical storms over the entire basin were maximized to determine the maximum flood at these points which would result from storms occurring concurrently over the various sub-basins. This procedure resulted in a smaller flood than would be produced by routing the probable maximum flood for each sub-basin to the downstream point, since probable maximum floods cannot be expected to occur concurrently over each sub-basin. The Muskingum method of routing floods was used. This method allows for the effect of valley storage.

Reliability of Probable Maximum Flood Estimates

3.36 The probable maximum flood is an estimate and as such is subject to the same limitations as all estimates: inadequacy of data and

Table 3-4

SUMMARY OF FLOOD PEAKS FROM MAXIMIZED HISTORICAL STORMS

Maximized Peak Flow from Area above Indicated Locations (cubic meters per second)							
Date of Maximized Historical Storm	Eski Mosul Damsite	Bekhme Damsite	Dokan Dam	Derbend-i- Khan Dam	Samarra	Baghdad	Below Mouth of Diyala
Feb. 7-12, 1941	-	-	-	-	28,400	22,000	24,500
Nov. 15-24, 1942	30,200	21,300	-	-	36,500	34,000	36,000
Dec. 18-Jan. 6, 1946	-	-	-	-	-	-	31,600
Feb. 13-18, 1946	-	-	17,500	-	-	-	-
Mar. 10-15, 1946	-	-	16,500	-	-	-	-
Dec. 22-30, 1949	28,900	-	-	23,400	30,200	26,600	28,900
Jan. 8-14, 1950	-	-	17,100	-	-	-	-
Mar. 4-10, 1950	-	22,600	-	-	-	-	-
Feb. 17-22, 1951	-	-	17,000	-	-	-	-
Feb. 2- 6, 1952	28,900	19,500	16,000	17,800	35,000	30,400	34,800
Feb. 4-11, 1953	28,900	-	-	-	-	-	-
Feb. 17-20, 1953	-	-	-	24,100	-	-	-
Feb. 19-24, 1954	-	-	14,900	22,600	-	-	-
Mar. 23-27, 1954	-	-	14,600	25,100	-	-	-
Adopted Value of Probable Maximum Flood	30,000	23,000	18,000	25,000	37,000	34,000	36,000
Equivalent Creager's "C"	94	103	91	111	93	82	82

3-15

inaccuracies of procedures. The assumptions and techniques used in the computation procedures are not new, having been used in previous studies and having gained acceptance after critical review. However, the approximations necessary do reveal certain weaknesses in the study which merit some discussion, as follows:

- a. The isohyetal patterns of historical storms were based on fewer precipitation stations than desirable. This could introduce either positive or negative errors. Since the largest runoff-producing storm was ultimately used, the probability exists that the storm used was one having a positive error; i. e., it was larger than the actual storm and is therefore on the conservative side.
- b. The maximization factors are dependent on dewpoint and wind data. These data were rather limited. However, the seasonal curves used in the maximization process were enveloping curves of historical points, and this procedure tends to offset any deficiencies in data.
- c. The maximized storms for any one basin might be deficient because of lack of storm experience in that basin. Accordingly, several basins were grouped together and enveloping values used for all basins in each group. This resulted in substantial over-envelopment of many of the maximized points.
- d. The data for snowmelt computations were extremely limited, and it was necessary to use some information from comparable areas in the United States. A conservative approach employing envelopes of historical data, critical melting temperatures, etc. was used in this procedure. Since the peak snowmelt contribution represented only six to thirteen percent of the probable maximum flood peak, a sizable error in the snowmelt estimate would introduce only a slight error in the flood peak estimate.

- e. Retention loss data were nonexistent. This led to use of data from the United States. The losses used were near the lowest measured in the entire U. S. experience (the lowest losses being experienced in areas not comparable to Iraq) and are believed to be somewhat lower than would have been used if fully adequate data had been available.
- f. Detailed flood hydrographs were not available for development of reliable unit hydrographs. Synthetic unit hydrographs were developed, but the procedures used are fairly well proven.

3.37 In practically all of the above cases the lack of data resulted in conservative assumptions. The compounding of these assumptions, which results from assuming concurrent occurrence of the various critical factors involved, tends to result in a final estimate which, in our judgement, has a high probability of being on the conservative side.

Flood Frequency

Frequency of Flood Peaks

3.38 Engineers concerned with the design of structures on or near rivers and those concerned with river control are interested in the probability of floods of various sizes. In the planning of reservoirs this information is needed to arrive at decisions on the degree of flood protection to be provided. The information is also required for such design considerations as diversion of a river during construction of a control structure, highway drainage structures, canal cross-drainage facilities, etc.

3.39 Flood frequencies on other rivers have been discussed in paragraphs 3.10 to 3.12, and the general subject of flood frequency analyses is examined briefly in paragraphs 3.43 to 3.46. In the case of the Tigris

River Basin, we consider that limitations in data make estimates of probable flood magnitudes at longer recurrence intervals than 100 years more than usually hazardous. Our estimates of probable flood frequencies have accordingly been restricted to that period. Exhibit 12 shows frequency curves for various locations. Since the curves have been limited to only a slight extension beyond the period of record, they are not affected to a very large degree by the variation in methods of analysis that are possible. The basic data for the curves were estimated by correlations between the damsites and the points of observations, for which correlations are also shown on Exhibit 12. The curves are based primarily on these estimates for each individual damsite, analyzed by the Hazen procedure, but adjustments have been made on the basis of regional parameters to take into account the widest possible range of unusual occurrences that may have happened by chance in one basin but not in another.

3.40 The coefficient of skew (C_s) in the Hazen equation is generally believed to be indicative of the variability in the general climatic regime of the drainage basin. Since the general variability throughout the Tigris River Basin is believed to be about the same, we have assumed that C_s will be an average of the computed C_s for five tributary stations in the basin having relatively long periods of record. The main Tigris River stations were not included since Fatha is an integration of upstream locations and therefore considered to be a duplication and since Baghdad records do not in any case truly represent very high floods because of by-pass flow.

3.41 The values of the mean flood and the coefficient of variation (C_v), both of which are factors in the Hazen equation, are more dependent on local topography, drainage pattern, and other conditions peculiar to the basin. At the same time, we feel that these factors also have a variability

related to basin-wide characteristics. Accordingly, data were plotted relating these values to drainage areas, and mean curves were drawn. The values of mean flood and C_v used in our analysis were the average of the individually computed values and the values indicated by the curves. The relationships developed and the resulting flood frequencies are shown on Exhibit 12.

3.42 As indicated earlier, we consider that the limitations in data make it impracticable to estimate probable recurrence intervals of more than 100 years for floods in the Tigris River Basin. We can, however, say that for all basins studied the 50-percent values of probable maximum flood peaks appear to have an average recurrence interval of substantially more than 100 years. The 50-percent values of probable maximum 20-day volumes have very much shorter recurrence intervals of approximately 50 years. This difference is to be expected, since high volumes can result from only a heavy snowpack accompanied by a timely melting temperature, whereas high peaks require a number of critical factors to occur in a critical sequence.

Reliability of Flood Frequency Estimates

3.43 In discussing the reliability of flood frequency estimates, it is pertinent to examine the underlying assumptions made in computing a frequency curve and to assess the value of the result. The basic assumptions are:

- a. That each flood occurrence on the river under study is independent; that each occurrence is a random event having no connection with other events in the series;
- b. That all the flood occurrences are homogeneous and members of one family;

- c. That the recorded floods are representatives of future floods.

3.44 The first assumption is subject to conflicting opinions. Hurst has presented data which indicate that annual precipitation, tree rings, clay varves, etc., tend to occur in groupings of high and low values. He also shows this trend for annual riverflow volumes. There is wide acceptance, although far from universal agreement, that annual volumes exhibit this tendency. On the other hand, there is a great deal of data throughout the world which tends to indicate that individual large storm occurrences are random events, not related to annual volumes. The annual flood peaks of mountain rivers in Iraq are practically always due to individual storms superimposed on a snowmelt base. While there is some variability in the snowmelt base, the greatest factor in the magnitude of the peak flow is the size of the rain-flood component. Therefore, we have concluded that peak values for Iraq rivers can reasonably be assumed to be random events.

3.45 Our conclusions on the second basic assumption are related to the first. Since the variability from year to year in peak discharges on the Tigris and its tributaries can be attributed primarily to the storm component, we consider it not unreasonable to assume that all such occurrences are members of one family. However, Hazen has suggested that very great and rare flood peaks have a special character outside a river's normal family of flood occurrences.

3.46 The third basic assumption (that the historical records are representative of the future) introduces some doubt. Even when events are random, groupings of high and low values do occur. It can be shown mathematically that if 10,000 years of record were available, the "100-year flood" would have a probable distribution as follows:

37 centuries would have no "100-year flood"	
37 centuries would have one "100-year flood"	= 37 such floods
18 centuries would have two "100-year floods"	= 36 such floods
6 centuries would have three "100-year floods"	= 18 such floods
1.5 centuries would have four "100-year floods"	= 6 such floods
<u>0.5 centuries would have six "100-year floods"</u>	<u>= 3 such floods</u>
100 centuries would have	100 such floods

3.47 Thus, there is an appreciable chance that the period of record we have considered is not representative of the future. As a means of effectively lengthening the period of record (and thereby reducing the chances of the period's being unrepresentative) we have used the Hazen concept of taking together the floods on all streams in the basin for developing the factors to determine the frequency curves. This procedure cannot be considered as increasing the effective length of record to the total of the lengths of the individual records, since there must exist some general correlation between flood occurrences in the individual basins. However, the effective length of record does become somewhat longer than the longest individual record, to an extent represented by the amounts that individual occurrences in separate basins do not follow a perfect correlation. Therefore, we believe we have taken the best precautions to eliminate the possibility of the period's being unrepresentative; at the same time this possibility must still be distinctly recognized.

3.48 The necessity of introducing correlations between flows at gaging stations and flows at the damsites, as required for Bekhme, Dokan, and Derbend-i-Khan, inevitably introduces some error. The periods of concurrent record at the gaging stations and the damsites are relatively short for development of the correlations. However, while individual

points show great deviations for the lower peaks, the values exceeding the mean annual flood are fairly consistent. Also, there is a general consistency between basins when the correlation curves are shown on a dimensionless basis, as is indicated on Exhibit 12. The deviation from complete consistency between basins has been partially adjusted, as indicated. It can be further stated that in a probability analysis, deviation of individual points is not highly significant as long as the general relationship is valid. We believe that possible errors in the frequency curve due to the necessity of converting flows from the gaging station to the damsite are not large.

3.49 To summarize, we believe that the probability curves shown on Exhibit 12 are the best that can be made with the available data and that they are a reasonable representation of the frequencies of occurrence to be expected. The possibility exists, however, that the three basic assumptions mentioned in paragraph 3.43 are not entirely valid, and this fact must be considered in any use to which our estimates of flood frequency are put.

Flood Volumes

Maximum 20-Day Flood Period

3.50 The relation of flood peak and volume varies considerably, but it was desirable to define a fixed relation in order to make all comparisons of floods consistent. The relations of historical peaks and the accompanying 20-day volumes were plotted as percentages of probable maximum peak and 20-day volume. The curve, shown on Exhibit 12, was drawn to allow estimation of a peak-volume relation favoring high flood volumes and extending to probable maximum peak and volume. The

historical points covered a range up to 62 percent of the probable maximum 20-day volume and 38 percent of the probable maximum peak flow.

3.51 Synthetic floods of magnitude greater than historical but smaller than the probable maximum were computed by use of the peak-volume relation. A method (described in Appendix C) was developed for computing the shape of hydrograph to correspond to a given flood peak. There is, of course, no fixed relation between flood peak and 20-day hydrograph shape. However, it was desirable to establish and use such a relation for the purpose of consistency in analysis of flood-control benefits.

Seasonal Floods

3.52 For purposes of flood routing, it was necessary to make some assumptions about the maximum seasonal runoff, to obtain an estimate of the storage reached at the time of the start of the maximum 20-day flood period. The probable maximum seasonal flood that we have devised is not purported to be highly reliable, but is believed to be of sufficient accuracy for this purpose.

3.53 Frequency analyses were made of historic seasonal flood volume, using the period of January through June inclusive. The curves were adjusted to take into account regional characteristics, in a manner similar to that used for frequencies of flood peaks. The curves were then extrapolated to obtain an estimate of the probable maximum flood, assuming that the extrapolated curve, when plotted on logarithmic paper, would deviate from a straight line to become asymptotic to a maximum volume at a recurrence interval of about 10^7 years. Some support was given to the extrapolation by an analysis of the maximum snow water equivalent curves on Exhibit 11. The pattern of the flood hydrograph was assumed to follow

that of the 1954 flood, except that the probable maximum 20-day period replaced the maximum 20 days of the 1954 flood.

CHAPTER IV
FLOOD-CONTROL OPERATIONS

Summary
Basic Assumptions
Flood Routings
Conclusions

Chapter 4

FLOOD-CONTROL OPERATIONS

Summary

4.1 Three series of flood-control operations were carried out, as follows:

Series A. Flood-routing studies to determine the effects of the various reservoirs on the flood peaks below reservoirs.

Series B. Flood-routing studies to determine the effects of various combinations of reservoirs on the flood peaks at Samarra.

Series C. Typical flood-routing studies to determine the peak flood at the Diyala-Tigris confluence for various additions to the existing reservoir system. This series is presented only to obtain graphical examples of typical flood-routing procedures and results.

4.2 The results of Series A are presented in tabular form in Table 4-1 and in graphical form in Exhibit 13. The results of Series B are presented in Table 4-2 and Exhibit 14. The flood-routing studies of Series C are presented in graphical form in Exhibits 15 through 20.

4.3 Detailed descriptions of the basic data used, dam and reservoir characteristics, and procedures of study are given in Appendix C.

Basic Assumptions

Reservoir Characteristics and Capabilities

4.4 Data on the relationship between elevation and reservoir volume and discharge capability for Derbend-i-Khan, Dokan, and Bekhme reservoirs

Table 4-1

EFFECT OF RESERVOIRS ON FLOOD PEAKS BELOW

RESERVOIRS

Reservoir	Irrigation Level	Characteristics of Reservoirs				Peak of Flood (cusecs)					
		Normal Maximum		Flood-Control Drawdown (milliards)	Probable Maximum	75% Probable Maximum		50% Probable Maximum		Uncontrolled	Controlled
		Elevation (meters G.T.S.)	Operating Level Volume (milliards)			Uncontrolled	Controlled	Uncontrolled	Controlled		
1. High Fatha	High	178.0	24.0	7.0	37,000	27,800	10,000	18,500	9,800	18,500	9,800
	Intermediate	178.0	24.0	12.0	37,000	27,800	10,000	18,500	9,800	18,500	9,800
2. Intermediate Fatha	Intermediate	172.5	18.0	6.0	37,000	27,800	10,000	18,500	9,900	18,500	9,900
	Low	172.5	18.0	11.2	37,000	27,800	10,000	18,500	9,800	18,500	9,800
3. Low Fatha	Low	165.0	11.8	5.0	37,000	27,800	10,000	18,500	9,900	18,500	9,900
4. High Eski Mosul	High	335.0	13.15	5.0	30,000	22,500	6,000	15,000	5,000	15,000	5,000
	Intermediate	335.0	13.15	6.8	30,000	22,500	5,000	15,000	5,000	15,000	5,000
5. Intermediate Eski Mosul	Intermediate	328.0	10.26	3.9	30,000	22,500	8,000	15,000	5,800	15,000	5,800
	Low	328.0	10.26	5.4	30,000	22,500	5,000	15,000	5,000	15,000	5,000
6. Low Eski Mosul	Low	320.0	7.65	2.8	30,000	22,500	10,500	15,000	5,000	15,000	5,000
7. High Bekhme	High	550.0	8.30	2.0	23,000	17,200	8,300	11,500	4,000	11,500	4,000
	Intermediate	550.0	8.30	4.5	23,000	17,200	6,400	11,500	4,000	11,500	4,000
8. Low Bekhme	Low	500.0	2.97	2.0	23,000	17,200	13,000	11,500	4,800	11,500	4,800
9. Dokan	-	511.0	6.82	1.5	18,000	13,500	2,400	9,000	2,000	9,000	2,000
10. Derbend-i-Khan	-	485.0	3.00	0.5	25,000	18,800	10,300	12,500	7,700	12,500	7,700

Table 4-2

EFFECT OF RESERVOIRS ON FLOOD PEAKS

AT SAMARRA

Characteristics of Reservoirs										Peak Flood at Samarra (cumecs)			
Reservoir	Irrigation Level	Normal Maximum			Maximum		Usable Drawdown Surchage (milliards)	Probable Maximum Uncontrolled	75% Probable Maximum Uncontrolled	50% Probable Maximum Uncontrolled	Controlled	Uncontrolled	Controlled
		Elevation (meters G.T.S.)	Operating Level	Volume (milliards)	Flood-Control	Drawdown (milliards)							
1. Dokan	-	511.0	6.8	1.3	1.5	1.3	37,000	35,700	27,750	23,600	18,500	15,800	
2. Following Reservoirs Added to Dokan:													
A. High Fatha	High Intermediate	178.0	24.0	7.0	2.7	2.7	37,000	15,000	27,750	10,000	18,500	9,800	
B. Intermediate Fatha	Intermediate Low	172.5	18.0	6.0	3.5	3.5	37,000	15,000	27,750	10,000	18,500	9,900	
C. Low Fatha	Low	165.0	11.8	5.0	3.4	3.4	37,000	18,000	27,750	10,000	18,500	9,900	
D. High Eski Mosul	High Intermediate	335.0	13.15	5.0	3.7	3.7	37,000	18,100	27,750	14,200	18,500	11,300	
E. Intermediate Eski Mosul	Intermediate Low	328.0	10.26	3.9	3.5	3.5	37,000	18,700	27,750	14,900	18,500	11,200	
F. Low Eski Mosul	Low	320.0	7.65	2.8	3.2	3.2	37,000	19,200	27,750	14,400	18,500	10,900	
G. High Bekhme	High	550.0	8.30	2.0	0.5	0.5	37,000	29,000	27,750	16,600	18,500	12,900	
H. Low Bekhme	Low	500.0	2.97	2.0	0.5	0.5	37,000	32,500	27,750	19,600	18,500	14,100	
I. High Eski Mosul and High Bekhme	High	335.0	13.15	5.0	3.7	3.7	37,000	15,800	27,750	12,400	18,500	9,700	
J. Intermediate Eski Mosul and High Bekhme	Low High	328.0	10.26	5.4	3.5	3.5	37,000	15,400	27,750	12,300	18,500	10,100	
K. Low Eski Mosul and Low Bekhme	Low Low	320.0	7.65	2.8	3.2	3.2	37,000	17,400	27,750	12,600	18,500	10,500	
L. Low Eski Mosul and High Bekhme	Low High	320.0	7.65	2.8	3.2	3.2	37,000	17,400	27,750	12,600	18,500	10,500	

were taken from information in the consultants' project planning reports or contract drawings. Similar data for Eski Mosul and Wadi Tharthar reservoirs were taken from preliminary data furnished by consultants. Area data for Fatha Reservoir were taken from the Irrigation Development (Haigh) Commission Report. Reservoir area-volume curves are shown on Exhibit 21.

4.5 The normal maximum operating levels of Derbend-i-Khan and Dokan were obtained from construction drawings. Different possibilities of maximum operating levels were studied for Bekhme, Eski Mosul, and Fatha. For the most part these levels were also studied by the consultants.

4.6 The normal maximum operating level is defined as the maximum level to which water will be stored for irrigation purposes. Joint use of storage space for irrigation and flood control was considered at all reservoirs, on the basis of rule curves of drawdown for flood control during the flood season. Voluntary storage for flood control above the normal maximum operating level was not considered for Bekhme, Dokan, or Derbend-i-Khan reservoirs. Some temporary storage for flood-control purposes above the normal maximum operating level was allowed at Fatha and Eski Mosul reservoirs. However, as discussed later, this space was not operated as freely for flood control as the joint use space.

4.7 The discharge capacities of the various dams were based on information in consultants' planning reports, except for Fatha Reservoir, where the assumed capacity was based on estimates by the Hydrological Survey. The capacities, indicating combined capacities of irrigation outlets and spillway, are shown on Exhibit 21. The structures, including discharge characteristics, are described in detail in Appendix C.

Rule Curves

4.8 A rule curve represents the drawdown that must be made for flood-control purposes (if discharge capacity is sufficiently in excess of inflow) at specific times of the year. It also represents the limit on storage for irrigation purposes at those specific times. The rule curves used in our studies were based on recommendations of consultants in project planning reports and on preliminary estimates made by the Hydrological Survey of refilling ability of reservoirs with proposed irrigation developments. Various possibilities for rule curves were studied for some of the reservoirs.

4.9 The period adopted for maximum drawdown of all reservoirs occurs between 1 January and 1 April, except at Dokan, where the maximum drawdown period is from 1 November to 1 March. Drawdown of all reservoirs then decreases to zero on 1 June.

4.10 The rule curves for Derbend-i-Khan and Dokan were predicated on assured filling immediately prior to the critical period for irrigation. For Fatha, Eski Mosul, and Bekhme, flood operation studies were also made with rule curves of that type; in addition, rule curves requiring further drawdown were studied, thus providing extra flood control with some detriment to irrigation. At each of the latter reservoirs, drawdown to three levels was studied; these levels are referred to as "high irrigation," "intermediate irrigation," and "low irrigation." The various possibilities of normal maximum operating levels and flood storage allocations that were studied are shown graphically on Exhibit 21 and are summarized in Tables 4-1 and 4-2. Details of the rule curves are discussed in Appendix C.

Flood Hydrographs

4.11 For all series of flood routings it was necessary to determine the reservoir levels at the start of the maximum 20-day flood period for the particular flood being routed. This was done by assuming seasonal hydrographs which were derived as described in Chapter 3 and Appendix B. Seasonal floods were developed to be used in conjunction with the probable maximum, 75 percent of probable maximum, and 50 percent of probable maximum flood peaks. This seasonal flood hydrograph was then routed through the system of reservoirs to obtain the reservoir levels at the start of the peak flood.

4.12 Estimates were also required for the maximum 20-day flood hydrographs to be used in conjunction with the probable maximum, 75 percent of probable maximum, and 50 percent of probable maximum flood peaks. The estimating procedures, described in Chapter 3 and Appendix B, were different from those used in the derivation of the seasonal flood hydrograph, and they also varied from basin to basin.

4.13 Most of the seasonal flood-control operations were carried out on a 24-hour basis. Six-hour units of time were used for the peak 24-hour portion of the flood. Inspection of flood routings indicated that a minimum of 12 hours elapses before any change in flows at upstream dam-sites is reflected in Samarra flows. It was therefore assumed that flows at Samarra would be known 12 hours in advance. No other foresight was assumed.

4.14 Operations followed the rule curves as closely as possible. In many cases storage above rule curve elevation resulted from discharge capacities too low to draw the reservoir down to rule curve level.

Flood Routings

Series A, Effect of Reservoirs on Flood Peaks Below Reservoirs

4.15 This series of flood routings was carried out for the five "on-stream" reservoirs, namely, Eski Mosul, Bekhme, Dokan, Fatha, and Derbend-i-Khan, using for each the 100-percent, 75-percent, and 50-percent probable maximum flood.

4.16 The only criteria used in this series of flood routings were those set up to provide local flood protection. The release limitations used are listed in Table 4-3 under the heading "A." The results of these flood routings are presented in Table 4-1 and are shown graphically on Exhibit 13.

Series B, Effect of Reservoirs on Flood Peaks at Samarra

4.17 This series of flood routings was carried out for the existing system and for the existing system plus a variety of combinations of reservoir additions to the system. The routings were made for 100 percent, 75 percent, and 50 percent of probable maximum flood at Samarra.

4.18 The primary objective of the flood-control operations was to limit the flow at Baghdad to an amount which could be safely contained in the Tigris channel. The operations attempted to limit the discharge of the Tigris at Baghdad to 4000 cumecs, to correspond to current practice in operation of Samarra Barrage. It was assumed, however, that the channel through Baghdad is capable of passing 8000 cumecs. Discharge capacity of the Wadi Tharthar diversion channel was assumed to be 9000 cumecs^{1/}, with 10,000 cumecs assumed as the capacity of the barrage on the Tigris.

^{1/} After the studies were completed, it was reported by NEDECO (Consultants for the Tharthar Reservoir Project) that they estimate the capacity of the present Tharthar diversion channel to be 7000 cumecs only.

Table 4-3

RESERVOIR OPERATING RULES USED IN FLOOD ROUTING STUDIES

Reservoirs	Reservoir Release Limitations				
	A. For Local Protection		B. For Downstream Protection		
	Reservoir Level	Allowable Release	Indicated Flow at Samarra 12 Hours Hence	Reservoir Level	Operation
1. Eski Mosul					
(a) Overflow Spillway	Rule Curve (normal maximum)	5,000 cumecs	10,000 cumecs	All levels	Release to limits in (A)
	Normal maximum - 2.0m. surcharge	5,000 cumecs	10,000 - 13,000 cumecs	Lower half joint use capacity	Store all inflows
	2.0m. surcharge - 4.0m. surcharge	6,000 cumecs			
	4.0m. surcharge - 5.0m. surcharge	8,000 cumecs			
	Above 5.0m. surcharge	Full spillway capacity	10,000 - 13,000 cumecs	Upper half joint use capacity and above	Release to limits in (A)
(b) Low Level Spillway	All levels	Full spillway capacity	13,000 cumecs	Below normal maximum	Store all inflows
2. Bekhme	Rule Curve (normal maximum)	4,000 cumecs	13,000 cumecs	Above normal maximum	Release to limits in (A)
	Above normal maximum	Full spillway capacity			
3. Dokan	All levels	Full spillway capacity			
4. Fatha					
(a) High Dam	Rule Curve (normal maximum)	10,000 cumecs			
	Normal maximum - 0.5m. surcharge	10,000 cumecs			
	0.5m. surcharge - 0.7m. surcharge	13,000 cumecs			
	Above 0.7m. surcharge	Full spillway capacity			
(b) Intermediate Dam	Rule Curve (normal maximum)	10,000 cumecs			
	Normal maximum - 2.0m. surcharge	10,000 cumecs			
	2.0m. surcharge - 3.0m. surcharge	13,000 cumecs			
	3.0m. surcharge - 3.5m. surcharge	15,000 cumecs			Not Applicable
	Above 3.5m. surcharge	Full spillway capacity			
(c) Low Dam	Rule Curve (normal maximum)	10,000 cumecs			
	Normal maximum - 2.25m. surcharge	10,000 cumecs			
	2.25m. surcharge - 4.0m. surcharge	13,000 cumecs			
	4.0m. surcharge - 4.5m. surcharge	15,000 cumecs			
	Above 4.5m. surcharge	Full spillway capacity			
5. Derbend-i-Khan	Rule Curve (normal maximum)	3,000 cumecs less average flow contribution over previous six hours from Middle Diyala Area (above Diyala Weir and below Derbend-i-Khan)			Not Applicable
	Above normal maximum	Full spillway capacity			

4.19 Various capacities of the diversion channel to Wadi Tharthar have been estimated by different authorities, ranging from 6000 to 9000 cumecs. However, if the river is operated for many years to divert all flows above 4000 cumecs, the channel at Baghdad will suffer gradual deterioration in discharge capacity, until in the natural course of events its capacity reaches some value in the order of 4000 cumecs.

4.20 Baghdad was considered to be safe if the inflow peak to Samarra from a particular flood and reservoir combination was less than 13,000 cumecs. Inflow peaks between 13,000 and 17,000 cumecs indicate the chance of breaching of the bunds above Baghdad, the probability increasing with the magnitude of the peak. The distribution of flows between the Tigris and the Wadi Tharthar diversion channel was considered indeterminate when peak inflows to Samarra exceeded 19,000 cumecs, since that is the maximum combined capacity of the barrage and diversion channel.

4.21 To meet these objectives the reservoir release limitations shown in Table 4-3 (A and B) were formulated; they were used consistently throughout the Series B routings.

4.22 The results of the flood routings of Series B are presented in Table 4-2 and are shown graphically on Exhibit 14.

Series C, Effect of Reservoirs on Flood Peaks at the Diyala-Tigris Confluence

4.23 The flood used in this series was 80 percent of the probable maximum flood at the Diyala-Tigris confluence. The criteria used in this series were the same as used in Series B, as listed in Table 4-3. The results of the flood routings, which are presented only as examples, are shown in Exhibits 15 through 20.

Discussion of Results of Operation Studies

4.24 The flood-control capacity required from an upstream system of reservoirs to protect Baghdad is primarily dependent upon a policy decision as to the magnitude of flood to be protected against. Cost estimates for the various developments, which are outside the scope of this report, will undoubtedly affect the decision on the degree of protection to be provided. Cost data will also affect the decision as to which reservoir or reservoirs should be constructed. This chapter is limited to furnishing information on the degree of protection afforded by various systems.

4.25 The curves on Exhibit 14 do not indicate the inflow from the Adhaim and Diyala rivers that might be expected to occur concurrently with given floods at Samarra. The Adhaim and Diyala contributions will depend on the storm distribution over the drainage basin. Historically, most of the major flood peaks at Samarra, Baghdad, and the mouth of the Diyala River have occurred from storms centered over the upstream areas, so that the Adhaim and Diyala contributions to peaks at Baghdad and the mouth of the Diyala have been relatively small. This is also true of the probable maximum floods at the three locations, since they would result from storms that were centered upstream.

4.26 Although historical occurrences seem to favor floods originating from upstream storms, the possibility exists of storms being more equally distributed over the basin or being centered over the Adhaim-Diyala area. The 1954 flood resulted from this type of storm. Our computations indicate that probable maximum floods of 13,000 and 11,000 cumecks, respectively, can occur from the Adhaim and from the Diyala River drainage area below Derbend-i-Khan. While these floods cannot (for meteorological reasons) occur concurrently, the occurrence of either one with a

fraction of the probable maximum of the other would cause extreme difficulties at and downstream from Baghdad. Upstream reservoirs and Samarra Barrage can be operated to cut off all flows at Samarra to afford protection from all but the largest of Adhaim and Diyala floods, but complete protection obviously cannot be provided by such systems.

Conclusions

4.27 The operation studies on Exhibits 15 through 20 show the protection afforded Baghdad and downstream areas by various systems against a flood of 80 percent of the probable maximum, distributed fairly uniformly over the basin. Adequate protection is given to Baghdad, but the areas downstream would be subject to severe flooding. Because of the more strategic location of the Fatha Reservoir, the degree of protection given to Baghdad by systems that include Fatha is somewhat better than that afforded by those systems with upstream reservoirs. Systems with upstream reservoirs could control the 80-percent flood to about the existing channel capacity at Baghdad, but this would probably be inadequate with future deterioration of the river channel.

4.28 Exhibit 20 indicates that the Fatha Reservoir provides the best flood control for Baghdad. However, local flood control at Mosul is sacrificed if Fatha is constructed in lieu of Eski Mosul. Protection for Mosul can be obtained with a modest sacrifice in protection for Baghdad if Eski Mosul is selected.

4.29 The alternative possibilities for variation in storm distribution, reservoir systems and storage allocations, and operational decisions are extremely great in number. Determinations of the effect of only a few of the various systems on floods at Baghdad were made, most operations

being carried only as far as Samarra. In general, floods that can be controlled to about 13,000 cumecs at Samarra offer a high probability of protection for Baghdad, with the degree of protection being somewhat less for areas downstream. However, the possibility still exists for a damaging flood to originate in the Adhaim and Middle Diyala areas; such a flood could not be controlled by Tharthar and reservoir systems upstream from Samarra. The only means of affording complete protection from such floods is by flood-control reservoirs on these streams, capable of storing the relatively small volumes of their flood peaks. A small reservoir on the Adhaim River at the Damir Kapu site and a moderate-sized reservoir on the Diyala River at the Gibraltar site, both considered by the Haigh Commission, would accomplish this end.

Haigh
Reservoir

4.30 The operation studies on Exhibits 15 through 19 demonstrate that the operation of Samarra Barrage in extreme floods must be closely coordinated with Adhaim and Diyala flows. Rapid means of communication between Samarra Barrage and key points on these rivers will be essential. This problem is discussed further in Chapter 8.

4.31 The curves on Exhibits 13 and 14 are useful in judging the value of a reservoir for interim storage for flood control while irrigation demands are building up to their ultimate level. For example, a high Eski Mosul Dam might be used with an intermediate or low irrigation allocation prior to the build-up of full irrigation demands. The increase in flood control with such allocations over that with a high irrigation allocation is demonstrated by the difference in the appropriate curves. The curves showing the degree of control with other reservoirs in the system indicate when other reservoirs would be needed to give the same degree of flood protection as can be afforded by a high Eski Mosul Reservoir during the interim stage of development.

4.32 It must be stressed that the flood-control studies were made primarily for the purpose of comparing the benefits of various reservoir systems. The actual figures obtained in the studies for the controlled peaks are those which would result from the particular seasonal and peak hydrographs used in the computations. Other floods with the same peaks but different hydrographs would, of course, give different values for the controlled peak. The results do, however, give a good comparison of the flood protection afforded by the various reservoirs studied.

4.33 The reader will have noted that no detailed computations were made for control of the record flood of 26 March 1954, except insofar as its accompanying storm was used to simulate the major storm preceding a maximum storm and flood. Inspection of the 1954 flood flow data showed that the flood could have been safely handled by the existing control facilities of the Tharthar Flood Escape and Dokan and Derbend-i-Khan reservoirs. The 1954 flood had practically the highest peak at Fatha and certainly the greatest volume of any flood on which there are reliable data. The scanty data of the 1907 flood suggest such a flood might have overstrained the existing facilities, possibly not with respect to Baghdad but rather in areas downstream.

CHAPTER V

IRRIGATION STUDIES

Summary

Definitions

Basic Assumptions

Method of Study

Basic Study Period

Water Resources

Water Usage

Other Basic Data and Operating Criteria

Results of Irrigation Studies

Validity of Results

Chapter 5

IRRIGATION STUDIES

Summary

5.1 Operation studies on a monthly basis were made of the irrigation water usage that could be supported after completion of Dokan and Derbend-i-Khan reservoirs and with other projected reservoirs added to the system. A total of about 175 studies were made of alternative reservoir systems to determine the level of irrigation development that each could sustain when operated to meet defined patterns of monthly irrigation requirements. The reservoirs studied are shown in schematic form on Exhibit 22, together with certain link canals between tributaries.

5.2 Results of the operation studies were compared on the basis of the ability of alternative systems to meet irrigation requirements, the amount of water surplus to irrigation requirements that would flow out of the system, and the amount of water lost to evaporation. A summary of the results is given in Table 5.1 and is shown graphically on Exhibits 23 and 24. Typical operation studies are shown graphically on Exhibits 26, 27, and 28.

5.3 Details of the basic assumptions used in the studies, the basic data and their limitations, the method of study, and the conclusions reached are given in this chapter. A detailed description of the method in which an electronic digital computer was used in the studies is given in Appendix D.

Definitions

5.4 "Critical period" means the period which limits "firm irrigation yield." It is the period from the start of reservoir drawdown to the time of minimum reservoir content. Mass curve analyses indicated that this period began in June 1929. The duration of the period depends upon the amount and location of reservoir storage being provided. The maximum length of the critical period that occurred in the systems studied was 78 months (June 1929 to November 1935).

5.5 "Basic study period" is the period used for comparison of alternative reservoir systems; it extends beyond the critical periods to May 1937, making a total period of eight years.

5.6 "Firm irrigation yield" means the annual delivery of irrigation water (not including any reduction for "tolerable shortage") that a system could have ensured during the basic study period.

5.7 "Tolerable shortage" means the reduction from the firm irrigation yield which is permitted during specified limited periods.

5.8 "System spills" means all amounts of water, originating from reservoir spills and uncontrolled river flows, that are surplus to the firm irrigation yield of a system. Such spills might be useful for other than normal irrigation purposes in lower Iraq and on the Shatt-el-Arab.

5.9 "Existing system" means the Dokan and Derbend-i-Khan reservoirs, which were under construction at the time the studies were made and were completed by the time of writing of this report, plus the Lesser Zab-Diyala link canal.

Basic Assumptions

5.10 A number of operating conditions were assumed in setting up the studies. The results shown on Table 5.1 and Exhibits 23 and 24

are fully valid only for these conditions, of which the principal are:

- a. That the basic study period is suitable as a basis for design.
- b. That reservoirs are operated solely to obtain the highest firm irrigation yield, with the exception of systems involving Wadi Tharthar, where concessions were made to flood control.
- c. That the assumed reservoir rule curves are adopted and strictly adhered to.
- d. That the future irrigation water requirements, with respect to distribution by months and project areas, are as listed in Table 5.2 and 5.3.
- e. That the assumed tolerable shortages are adopted.
- f. That the basic data on reservoir capacity, stream-flow, evaporation, etc., are correct.
- g. That the historical water resources of the Tigris River system (without the Diyala tributary) are represented by the Baghdad flow record, subject to adjustments for the estimated difference between historical and future losses between Fatha and Baghdad.
- h. That there is no transmission gain or loss between Baghdad and Kut.
- i. That if a power plant is not installed at Dokan Dam, valves will be fitted to existing penstocks if needed to increase the outlet capacity for irrigation releases.
- j. That in all systems a link canal would be operating between the Lesser Zab and Diyala rivers.

Table 5.2

**1975 IRRIGATION REQUIREMENTS, TIGRIS RIVER SYSTEM,
AS USED IN OPERATION STUDIES**

(Monthly Values in Cubic Meters Per Second and Annual Totals in Billiards of Cubic Meters)

	<u>Jan.</u>	<u>Feb.</u>	<u>Mar.</u>	<u>Apr.</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>	<u>Dec.</u>	<u>Total</u>
For Navigation below Kut	325	325	325	325	325	325	325	325	325	325	325	325	10.25
Extra for Navigation	<u>203</u>	<u>184</u>	<u>129</u>	<u>82</u>	<u>244</u>	<u>143</u>	<u>141</u>	<u>152</u>	<u>174</u>	<u>239</u>	<u>159</u>	<u>197</u>	<u>5.38</u>
Irrigation below Kut	122	141	196	243	81	182	184	173	151	86	166	128	4.87
At Kut, Dujaila Canal	18	26	31	29	26	24	24	23	18	14	20	18	0.71
Gharraf, Present Area	103	144	192	200	150	153	142	135	89	80	113	109	4.26
Gharraf, Extension Project	36	55	80	71	68	92	93	89	64	49	45	40	2.03
Tigris, Kut to Diyala Confluence	<u>62</u>	<u>80</u>	<u>103</u>	<u>101</u>	<u>79</u>	<u>114</u>	<u>122</u>	<u>115</u>	<u>82</u>	<u>64</u>	<u>84</u>	<u>75</u>	<u>2.84</u>
Subtotal below Samarra													
Irrigation Only	341	446	602	644	404	565	565	535	404	293	428	370	14.71
With Navigation below Kut	544	630	731	726	648	708	706	687	578	532	597	567	20.09
Tigris, Samarra to Fatha													
Ishaqi Project	17	20	30	29	25	38	40	38	22	20	26	19	0.85
Nahrwan Project ^{1/}	20	22	31	33	32	42	44	42	29	25	28	20	0.97
Tigris above Fatha ^{2/}													
Mosul Pumping, Eski Mosul East, Shimal and Zakho Projects	-3	-3	0	10	13	20	20	17	14	14	-1	-1	0.26
Jazira Project ^{3/}	<u>8</u>	<u>8</u>	<u>33</u>	<u>52</u>	<u>36</u>	<u>62</u>	<u>66</u>	<u>67</u>	<u>52</u>	<u>46</u>	<u>23</u>	<u>13</u>	<u>1.22</u>
Subtotal on Tigris													
Irrigation Only	383	493	696	768	510	727	735	690	521	398	504	421	18.01
With Navigation below Kut	586	677	825	850	754	870	876	851	695	637	663	618	23.39
Diyala River, Middle Diyala	5	11	15	24	21	36	35	33	19	19	21	9	0.65
Lower Diyala	<u>56</u>	<u>75</u>	<u>97</u>	<u>97</u>	<u>81</u>	<u>130</u>	<u>131</u>	<u>124</u>	<u>75</u>	<u>65</u>	<u>80</u>	<u>62</u>	<u>2.83</u>
Subtotal on Diyala	61	86	112	121	102	166	166	157	94	84	101	71	3.48
Lesser Zab River, Above Dokan	1	2	3	3	3	4	5	4	2	2	3	2	0.09
Hawija Canal	11	13	20	20	16	25	26	24	14	13	17	12	0.55
Adhaim Project ^{1/}	<u>27</u>	<u>31</u>	<u>46</u>	<u>48</u>	<u>45</u>	<u>63</u>	<u>66</u>	<u>63</u>	<u>40</u>	<u>35</u>	<u>41</u>	<u>30</u>	<u>1.41</u>
Subtotal on Lesser Zab	39	46	69	71	64	92	97	91	56	50	61	44	2.05
Greater Zab River ^{2/}													
Makhmour Project, Including Eski Kelek	3	8	13	13	12	22	23	19	9	8	13	8	0.40
Khazir River ^{2/}													
Gomel and Khazir-Gomel Projects	<u>-1</u>	<u>-1</u>	<u>0</u>	<u>6</u>	<u>10</u>	<u>14</u>	<u>16</u>	<u>15</u>	<u>10</u>	<u>9</u>	<u>1</u>	<u>-2</u>	<u>0.20</u>
SYSTEM TOTAL, Irrigation Only	485	632	890	979	698	1021	1037	981	690	549	680	542	24.14
Irrigation + Navigation	688	816	1019	1061	942	1164	1178	1133	864	788	839	739	29.52

^{1/} Losses on feeder canals to Nahrwan and Adhaim projects included.

^{2/} Net requirements for projects on Tigris above Fatha and on Greater Zab, Lesser Zab, and Khazir rivers after allowing for return flows.

^{3/} Jazira Project can be irrigated only if Eski Mosul Reservoir is included in system.

Table 5.3

**1985 IRRIGATION REQUIREMENTS, TIGRIS RIVER SYSTEM,
AS USED IN OPERATION STUDIES**

(Monthly Values in Cubic Meters per Second and Annual Totals in Billiards of Cubic Meters)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
For Navigation below Kut	225	225	225	225	225	225	225	225	225	225	225	225	7.10
Extra for Navigation	91	69	5	0	127	24	22	34	59	126	43	84	1.80
Irrigation below Kut	134	156	220	279	98	201	203	191	166	99	182	141	5.44
At Kut, Dujaila Canal	17	26	37	33	32	43	43	41	30	23	20	15	0.94
Gharraf, Present Area	120	160	240	280	140	210	210	200	160	110	190	140	5.67
Gharraf, Extension Project	53	81	118	104	100	135	137	131	94	72	65	49	3.00
Tigris, Kut to Diyala Confluence	97	124	161	158	123	193	190	179	112	100	147	101	4.43
Subtotal below Samarra													
Irrigation Only	421	547	776	854	493	782	783	742	562	404	604	446	19.48
With Navigation below Kut	512	616	781	854	620	806	805	776	621	530	647	530	21.28
Tigris, Samarra to Fatha													
Ishaqi Project	17	20	30	29	25	38	40	38	22	20	26	19	0.85
Nahrwan Project ^{1/}	33	38	54	55	49	69	71	67	44	39	49	35	1.59
Tigris above Fatha ^{2/}													
Mosul Pumping, Eski Mosul East, Shimal and Zakho Projects	-4	-3	2	19	24	37	39	34	26	23	-1	-1	0.51
Jazira Project ^{3/}	16	16	65	104	73	123	133	133	103	94	45	25	2.45
Subtotal on Tigris													
Irrigation Only	483	618	927	1061	664	1049	1066	1014	757	580	723	524	24.88
With Navigation below Kut	574	687	932	1061	791	1073	1088	1048	816	706	766	608	26.68
Diyala River, Middle Diyala	8	16	23	35	31	55	48	48	29	28	31	14	0.96
Lower Diyala	75	99	131	131	108	174	175	164	100	86	120	82	3.80
Subtotal on Diyala	83	115	154	166	139	229	223	212	129	114	151	96	4.76
Lesser Zab River, Above Dokan	1	2	3	3	3	4	5	4	2	2	3	2	0.09
Kirkuk Project	31	37	56	94	46	70	74	69	40	37	48	35	1.57
Hawija Canal	11	13	20	20	16	25	26	24	14	13	17	12	0.55
Adhaim Project ^{1/}	27	31	46	48	45	63	66	63	40	35	41	30	1.41
Subtotal on Lesser Zab	70	83	125	125	110	162	171	160	96	87	109	79	3.62
Greater Zab River ^{2/}													
Makhmour Project, Including Eski Kelek	6	12	23	20	17	36	35	33	13	11	21	9	0.62
Khazir River ^{2/}													
Gomel and Khazir-Gomel Projects	-2	-1	3	15	23	35	38	34	24	19	3	Nil	0.50
SYSTEM TOTAL, Irrigation Only	640	827	1232	1387	953	1511	1533	1453	1019	811	1007	708	34.38
Irrigation + Navigation	731	896	1237	1387	1080	1535	1555	1487	1078	937	1050	792	36.18

^{1/} Losses on feeder canals to Nahrwan and Adhaim projects included.

^{2/} Net requirements for projects on Tigris above Fatha and on Greater Zab, Lesser Zab, and Khazir rivers after allowing for return flows.

^{3/} Jazira Project can be irrigated only if Eski Mosul Reservoir is included in system.

- k. That in the case of the larger systems a method is available whereby water can be transferred from the Tigris or Greater Zab to the Lesser Zab-Diyala complex. (The link canal between the Greater and Lesser Zabs shown on Exhibit 22 is no longer practicable owing to a change in irrigation project diversion works, but there are other methods, described later, of accomplishing the same purpose.)

5.11 Since it cannot be assured that all of these conditions will actually exist, the effects of variations are examined and explained later in this chapter (paragraphs 5.99 through 5.124).

Method of Study

General Procedure

5.12 The studies were conducted by operating alternative reservoir systems with historical monthly streamflows and balancing reservoir inflows and storage, together with any uncontrolled river flows considered usable, against irrigation usage and water losses. This is a standard procedure in such studies. Water resources, water requirements, and use of storage can be analyzed in their relationship with each other only by this method.

Hold-Over Storage

5.13 All our reservoir operation studies were based on the philosophy of holding storage from periods of high natural river flows for use in periods of low natural flows. The storage capacity available on the Tigris River system makes implementation of this philosophy possible, and the wide range of the system's annual flows makes it desirable. It leads to an established farming population and agricultural pattern,

regular marketing arrangements, and economical canal and drainage networks. The other philosophy -- annual storage of each season's flood for use in the low river season immediately following -- has to be adopted on some river systems because of lack of adequate storage capacity for the annual flow, but the Tigris is more fortunate in this respect. Should studies for annual storage ever be desired, they are comparatively simple to conduct.

Periods Used in Studies

5.14 The principal aim of the studies was to determine the firm irrigation yield, with tolerable shortages, that could be delivered by each reservoir system studied. With hold-over storage, this is determined by the water resources available during the critical period; therefore, the performance of a system was judged on the results obtained by operating the system during the eight-year basic study period. The results give a reliable comparison of alternative reservoir systems, subject only to the qualifications stated later, in paragraphs 5.99 through 5.124.

5.15 Most of the studies were worked only for the eight years. The studies shown plotted on Exhibits 26, 27, and 28 and other studies for special purposes described in this and later chapters were worked for a 27-year period extending from June 1929 through May 1956. The longer period gave a picture of the general performance of typical systems for a much wider range of streamflow conditions.

Use of Electronic Computer

5.16 The many combinations of reservoirs to be studied necessitated a large number of operation studies, which, if performed by

manual methods, would have required a prohibitive amount of tedious work. Arithmetical errors would have been almost inevitable. Consequently, arrangements were made to use the facilities of International Business Machines (IBM) in London, who furnished a "650" electronic digital computer.

5.17 A special code was formulated in which each step of the operation studies was expressed as a mathematical computation that could be performed by the computer. The computer coding was performed by IBM after flow diagrams depicting the operations had been prepared by engineers of the Hydrological Survey. The conditions for each operation study were specified to the computer by a series of parameters. Once the code was formulated it was possible to work an operation study in a much shorter time and at considerably less expense than with manual methods. The net result of the use of the computer was an earlier completion of the studies, a greater coverage of possible variation, and a reduction in overall costs. A detailed description of the computer procedure is given in Appendix D.

5.18 The electronic computer not only worked the operation studies, but also printed the significant monthly and annual output data so that the results could be analyzed for many types of information. The most important data derived from the studies are presented in this report, but a large amount of other information also was obtained. The printed results of all the significant studies were retained in the Hydrological Survey files, which were handed over to the Director General of Irrigation.

Study Procedure

5.19 The method of making an operation study was to specify to the computer the delivery of a percentage of either the 1975 or 1985 irrigation

requirements. Other parameters were specified with the intention of enabling the reservoir system under study to deliver that percentage without causing unscheduled shortages, that is, shortages in excess of the permitted limits, explained later in paragraph 5.52. The full potential of a system was considered to be developed if no unscheduled shortages occurred and if all stored water was used by the end of the critical period for that system.

5.20 A study was worked by "trial and error" and was repeated until acceptable results were obtained. It would have been uneconomical to work the study on the computer until exact results were obtained, so adjustments were made manually to the parameters of the best study of a system to eliminate the effects of any remaining unscheduled shortages and of unused storage. The theoretically exact firm irrigation yield was then computed from the adjusted parameters.

5.21 The first step in the adjustment procedure was to determine the unused storage at the time of minimum total reservoir content and the amount of unscheduled shortages prior to that time. The difference in these two values was the excess or deficiency in firm irrigation yield. The ratio between this value and the total irrigation deliveries from stored water during the period prior to maximum drawdown was applied as an adjustment to the irrigation yields.

5.22 Wherever the manual adjustments were sufficiently large to cast doubt on the validity of the study, it was rerun on the computer with the adjusted parameters. The use of the electronic computer made this practice convenient and inexpensive and permitted more accurate results.

Basic Study Period

Critical Periods

5.23 The sum of the flows of the Tigris River at Baghdad and the Diyala River at Diyala Weir gives an index of the total water resources of the basin. This flow was determined with reasonable accuracy from January 1924 through September 1956. A mass diagram analysis was made of these flow data and of the estimated 1985 irrigation requirements to determine the critical period. The results of this analysis, shown on Exhibit 25, indicate that the period from June 1929 through November 1935 was the driest period since 1924.

5.24 More approximate data for Baghdad for the period of 1906 through 1923 (with some periods of missing record in these years) gave fairly conclusive evidence that none of the 1906-1923 period was as critical. Subsequent to completion of the studies, streamflows were substantially below the average of the historical record. Preliminary data available at the time of writing of this report indicate that the flows for the five water years ending September 30, 1962, were only about six percent higher than for a corresponding period starting with the 1930 water year. A comparison of flows for the two periods is given in Table 5.4.

5.25 Thus, while the dry period used in our studies was probably the most severe of any period occurring within the past 57 years, it does not appear to have been very exceptional. There is further discussion on the severity of the period in paragraph 5.100 to 5.109 under "Validity of Results."

Table 5.4

COMPARATIVE VOLUMES OF TIGRIS SYSTEM FLOWS
1930-35 AND 1958-62 LOW PERIODS

(Volumes in milliards)

Number of Years	1930-35 Period					1958-62 Period					1958-62 Cumulative as Percent of 1930-35
	Water Year	Tigris at Fatha	Diyala at Discharge Site	Total	Cumulative Total	Water Year	Tigris at Fatha	Diyala at Discharge Site	Total	Cumulative Total	
1	1929-30	18.0 ^{1/}	3.3	21.3	21.3	1957-58	33.1	5.2	38.3	38.8	180
2	1930-31	31.4	3.0	34.4	55.7	1958-59	26.9	5.5	32.4	70.7	127
3	1931-32	29.0	3.3	32.3	88.0	1959-60	30.6	2.5	33.1	103.8	118
4	1932-33	30.7	5.5	36.2	124.2	1960-61	25.6	5.1	30.7	134.5	108
5	1933-34	29.8	5.1	34.9	159.1	1961-62	30.0 ^{2/}	3.5	33.5	168.0	106
6	1935-36	32.9	2.7	35.6		1962-63	high flows in spring of 1963, volumes not yet known				-
5-Year Mean		27.8	4.0	31.8	-		29.2	4.4	33.6	-	-

^{1/} Estimated from Baghdad data.

^{2/} Estimated from data of first eight months of year.

Note: There were slight differences in irrigation diversions upstream of Baghdad and the Discharge Site in the two periods. The estimated annual diversions were about 0.3 milliards in 1930-35 and about 1.1 milliards in 1958-62.

Selection of Basic Study Period

5.26 In the case of some of the larger systems, the criteria adopted for determining years of tolerable shortages indicated shortages after November 1935, the end of the longest critical period in any of the systems studied. Therefore, a somewhat longer period extending to May 1937 was adopted as the basic study period so that all systems would be on the same basis for purposes of comparison. The basic study period was thus eight years, from June 1929 through May 1937.

Reservoir Content at Start and End of Basic Study Period

5.27 The use of a period starting in June 1929 was given further justification by studies which indicated that all reservoirs except Wadi Tharthar (when used for irrigation) and possibly Derbend-i-Khan^{1/} would be full on that date, thereby providing a definite starting point. Also, this date limited estimation of streamflows based on doubtful data to only a few months in 1929 and early 1930. As to the exception noted above for Wadi Tharthar, it was determined that Wadi Tharthar would be at flood rule curve content on April 1, 1929, but that streamflows during April and May of 1929 would not have been sufficient to fill the reservoir completely by June 1. The more reservoirs in addition to Wadi Tharthar there were in a system, the lower the content of Wadi Tharthar on June 1, since the April and May flows normally had to fill the joint use space in upstream reservoirs before adding to the contents of Wadi Tharthar.

^{1/} The data for high flows on the Diyala River previous to 1930 are very uncertain; see The Regime of the Rivers Euphrates and Tigris by M. G. Ionides, pp. 168-169.

5.28 In many of the studies, particularly those with large storage and high firm irrigation yield, the reservoirs did not refill until after the end of the eight-year basic study period. However, both the mass curve analysis of Exhibit 25 and the studies that were run for a 27-year period showed that all such systems would have refilled within a maximum of three years after May 1937, owing to a period of substantially more than average flows. Although drawdown at the end of the period would not be objectionable for the historical sequence of streamflows, it would certainly be objectionable in the event that the period was followed by a sequence of no more than average flows, which would not allow reservoirs to refill before recurrence of another dry period. Such an occurrence, of course, would represent conditions worse than historical.

Water Resources

Reservoir Inflows

5.29 Monthly streamflow data at the nearest gaging stations, developed as described in Chapter 2, were adjusted to compute inflows to the major reservoirs. The adjustments for Dokan and Bekhme reservoirs were made by the same methods as used by the consultants in their project planning reports. A revised method was developed for Derbend-i-Khan, using the following formula (based on monthly values):

$$\text{Derbend-i-Khan flow} = 0.8 \text{ Discharge Site flow} + 8 \text{ cumecs.}$$

The data for the Tigris River at Mosul were considered to represent inflow to Eski Mosul Reservoir without adjustment.

5.30 The data for Fatha were assumed to represent flows at Samarra as well as at Fatha. Future accumulation of records for the recently established river discharge station at Samarra may show significant gains or losses between Fatha and Samarra, which would alter the flows used for Samarra. The main effect of this would be a small change in power potential at Samarra or in operation of Wadi Tharthar Reservoir for irrigation storage.

Inflows Below Reservoirs

5.31 The usable system inflows below the reservoirs were computed as the sum of the flows of the Tigris at Baghdad (recorded) and the Diyala at Derbend-i-Khan (computed) less the sum of the computed inflows to Dokan, Bekhme, and Eski Mosul reservoirs, subject to two adjustments. These adjustments were (a) an allowance for flows that occur in such a manner as to be unusable for meeting irrigation requirements and (b) an allowance to adjust the historical river losses from historical to future conditions. These adjustments are discussed in detail in the following paragraphs.

Adjustment for Unusable Inflow

5.32 The inflows of the Adhaim River are almost entirely in spates (a term used to denote floods of short duration and relatively high peaks) and were considered unusable for irrigation. Therefore, the historical Adhaim flows were deducted from the computed gain in flow between the upstream reservoirs and Baghdad. The flows entering the Diyala River below Derbend-i-Khan Reservoir are of a similar nature, and these also were considered unusable. No arithmetic adjustment was necessary for the Diyala spates because the flow values used were those at Derbend-i-Khan.

5.33 In addition to the spates that occur on the Adhaim and the Diyala, drainage areas which were uncontrolled in some reservoir systems contributed historical flows in such a manner that the entire flow might not be usable. The computer studies were worked on a monthly basis, which did not allow for the considerable variations in streamflow that sometimes occurred during the month from these uncontrolled areas. The extent of the uncontrolled areas and the magnitude of unusable flow from this cause varies from study to study, being dependent on the reservoirs that are in the system. In systems including both Bekhme and Eski Mosul reservoirs, the unusable flow from this cause would be very small and was considered to be zero. Fatha Reservoir would of course control all drainage areas. For other systems the magnitude of unusable flow could not be determined from the computer studies without operation on a daily basis, which was impractical. Therefore, daily streamflow records during the eight-year basic study period were scrutinized and an adjustment developed by approximation to compensate for flows that appeared to be unusable.

Adjustments for River Losses

5.34 The first step in this adjustment was to introduce two "bookkeeping" terms to allow for the approximate historical river losses. The first bookkeeping term was for the difference between Fatha flow and the sum of the computed flows at the upstream reservoirs; the second was for the difference between Baghdad flow and the sum of Fatha and Adhaim flows. It was considered that the first difference was usable only below Fatha and the second only below Samarra. If either of the terms was negative, as was usually the case between Fatha and Baghdad, its value was treated in the operation studies as a water requirement which had to be replenished from usable water resources.

5.35 The second step in the river loss adjustment was to convert from historical to future conditions. This adjustment involved consideration of the relative reliability of the Baghdad and Fatha flow records. Flows at Baghdad were, of course, reduced by any breaches of upstream bunds (levees) during high floods. Also, greater adjustments for river losses are required if Baghdad flows are used. We recognized that the Fatha record would appear to be a truer representation since that gaging site is upstream of any breaches in bunds during high flood. However, the Fatha record has serious limitations, as explained in paragraphs 2.11 and 2.12 of Chapter 2, which would affect the accuracy of the usable inflows as well as the river losses. In addition, information from the Irrigation Directorate indicated that there were only very insignificant losses of water by breaches upstream of Baghdad during the basic study period and none during the critical period of all but the largest reservoir systems. Therefore, the Baghdad record was selected for use in the computer studies.

5.36 After the studies were well under way, reliable streamflow measurements made at Fatha by the Hydrological Survey enabled the relative merits of Fatha and Baghdad flows to be further considered. Differences between recorded streamflows at consecutive gaging stations on a river must always be treated with caution in computing apparent transmission gains or losses since the differences are usually small compared with the total streamflow values. Conclusions can be arrived at only from a large number of analyses which indicate a general and fairly consistent trend. The later data were sufficiently extensive for this purpose. After the studies were completed these data were utilized to make further, improved adjustments to allow for the changes in losses that it was estimated would occur under future operating conditions.

5.37 We concluded that flood flows, especially sharp spates in the winter months, resulted in historical losses appearing between Fatha and Baghdad without any breaches occurring. Losses during such periods appeared to have been as much as 25 percent of the mean monthly flow at Fatha. In recent years approximately half the apparent losses seem to have occurred between Fatha and Samarra; the extent to which heading-up by Samarra Barrage (completed in 1956) may have contributed to this loss cannot be determined from the information obtained to date.

5.38 A full explanation of the losses between Fatha and Baghdad would require very extensive investigations. They might be partly accounted for by water being absorbed during times of flood into the many islands and foreshores covered with vegetation which exist on the Tigris from Fatha to the Adhaim confluence. This water would later be lost by evaporation from the water table or by consumptive use by the vegetation during the slow recession period in the following summer. Also, a part might find its way through aquifers in old river channels, which are known to exist in the neighborhood of Samarra, to outfalls further downstream.

5.39 Whatever the explanation, the evidence indicates that there have occurred historically between Fatha and Baghdad losses which vary with the degree of daily fluctuations and the amount of flow in the river. Although the amounts of these computed losses are not fully reliable, the pattern of losses and the consideration of subsequent data lend support to the conclusion that adjustment is necessary. Obviously the losses under future conditions will vary according to the degree of control exercised by each reservoir system, with larger losses accompanying those systems that allow the greater range of flows in the river.

5.40 The estimates of loss in flow between Fatha and Baghdad as computed for the second bookkeeping item (Baghdad flows less the sum of the Fatha and Adhaim flows) were used to develop estimates of salvageable river losses that would result with different systems. The existence of Fatha Reservoir in a system would salvage the greatest amount, and estimates of salvaged water in such systems were made on the basis of nearly full recovery of the computed historical losses. Eski Mosul was estimated to result in salvage of 50 percent of that saved by Fatha, while Bekhme was estimated to save 20 percent of the Fatha salvage.

Effect of Bakurman Reservoir on Streamflow

5.41 The assumed 1975 and 1985 irrigation requirements included the Khazir-Gomel diversions, which would not be practicable without construction of the proposed Bakurman Reservoir. Therefore, this reservoir was assumed to exist for all studies using 1975 or 1985 irrigation requirements, including studies of the so-called "existing system," even though Bakurman Reservoir does not exist at present. The effect on Khazir River resources of the operation of this reservoir was obtained from the planning report prepared by the Kuljian Corporation, which indicated a small increase in summer flow and a small decrease in winter flow. The maximum effect on firm irrigation yield for any of the systems studied was only 0.2 milliards gain. The quoted yields for all systems should be reduced by between 0.1 and 0.2 milliards if Bakurman Reservoir is not constructed.

Water Usage

Types of Water Requirements

5.42 The water requirements used in the operation studies included those for irrigation and, in some cases, navigation. Residual flows available for rice flooding were determined in some studies, but rice flooding requirements were not specified in any study. The irrigation requirements were based primarily on data furnished by other consultants, with a small part based on information from the Irrigation Development (Haigh) Commission Report or on informal discussions with engineers experienced in Iraq irrigation.

5.43 Certain minimum flows, to satisfy "amenities of the river," were assumed for key points in the river system. These flows were ten cumecs on the Greater and Lesser Zab rivers, 30 cumecs on the Upper Tigris, and 150 cumecs at Samarra.

Irrigation Requirements

5.44 Irrigation requirements for intermediate and near ultimate conditions of development are shown in Tables 5.2 and 5.3. These are referred to as 1975 and 1985 conditions, respectively. They do not, of course, necessarily represent the future growth of irrigation development and are for purposes of classification only.

5.45 The 1985 requirements represent those for projects under investigation at the time of our studies. Where possible, the 1975 requirements reflect the known project construction schedules. In other cases the 1975 values were obtained by interpolation between estimated present and 1985 requirements.

5.46 Irrigation requirements for various areas are under continuing study by government agencies and other consultants. Some changes in estimated requirements were made by other consultants after the operation studies were well under way. The requirements were not changed in our studies since the main purpose was comparison of alternative systems of reservoirs and it was, therefore, important that the same data be used throughout.

5.47 The revisions in irrigation requirements were limited to 1985 conditions and are shown in Table 5.5 for record purposes. They differ from the values used in the studies only for the Diyala River and for the area below Kut. The changes are relatively small for the Diyala River, but the estimated requirements for the area below Kut were more than doubled, to represent an increase of 18 percent in the total demands on the system. This would have no significant effect on the firm irrigation yields shown on Table 5.1 and Exhibit 23.

Return Flows from Irrigation

5.48 Return flows from irrigation were allowed for on Tables 5.2 and 5.3 only for projects in northern Iraq. For projects on the Tigris below Fatha, we understand it is intended that most of the drainage water will be passed ultimately into large outfall drains discharging into Hammar Lake in southern Iraq. For much of the Lower Diyala area drains are already under construction intended to discharge ultimately into Haur Suwaicha northeast of Kut. Thus, there would be only a small proportion of return water entering the Tigris below Fatha. In any case most of the return water from projects below Fatha will be too saline to use again for irrigation purposes until many years have passed.

Table 5.5

**REVISED 1985 IRRIGATION REQUIREMENTS, TIGRIS RIVER SYSTEM
NOT USED IN OPERATION STUDIES**

(Monthly Values in Cubic Meters Per Second and Annual Totals in Millions of Cubic Meters)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Irrigation below Samarra													
Below Kut	182	285	373	412	463	600	629	563	413	311	201	165	12.10
At Kut, Dujaila Canal	17	26	37	33	32	43	43	41	30	23	20	15	.95
Gharraf, Present Area	120	160	240	280	140	210	210	200	160	110	190	140	5.68
Gharraf, Extension Project	53	81	118	104	100	135	137	131	94	72	65	49	3.00
Tigris, Kut to Diyala Confluence	<u>97</u>	<u>124</u>	<u>161</u>	<u>158</u>	<u>123</u>	<u>193</u>	<u>190</u>	<u>179</u>	<u>112</u>	<u>100</u>	<u>147</u>	<u>101</u>	<u>4.43</u>
Subtotal below Samarra	469	676	929	987	858	1181	1209	1114	809	616	623	470	26.16
Tigris Irrigation, Samarra to Fatha													
Ishaqi Project	17	20	30	29	25	38	40	38	22	20	26	19	.85
Nahrwan Project ^{1/}	33	38	54	55	49	69	71	67	44	39	49	35	1.59
Tigris above Fatha^{2/}													
Mosul Pumping, Eski Mosul East, Shimal and Zakho Projects	-4	-3	2	19	24	37	39	34	26	23	-1	-1	.51
Jazira Project ^{3/}	<u>16</u>	<u>16</u>	<u>65</u>	<u>104</u>	<u>73</u>	<u>123</u>	<u>133</u>	<u>133</u>	<u>103</u>	<u>94</u>	<u>45</u>	<u>25</u>	<u>2.45</u>
Subtotal on Tigris	531	747	1080	1194	1029	1448	1492	1386	1004	792	742	548	31.56
Diyala River													
Middle Diyala	12	13	21	28	25	33	36	34	28	29	22	12	.77
Lower Diyala	<u>69</u>	<u>80</u>	<u>116</u>	<u>135</u>	<u>112</u>	<u>145</u>	<u>157</u>	<u>148</u>	<u>127</u>	<u>129</u>	<u>103</u>	<u>71</u>	<u>3.66</u>
Subtotal on Diyala	81	93	137	163	137	178	193	182	155	158	125	83	4.43
Lesser Zab River													
Above Dokan	1	2	3	3	3	3	5	4	2	2	3	2	.09
Kirkuk Project	31	37	56	54	46	70	74	69	40	37	48	35	1.57
Hawija Canal	11	13	20	20	16	25	26	24	14	13	17	12	.55
Adhaim Project ^{1/}	<u>27</u>	<u>31</u>	<u>46</u>	<u>48</u>	<u>45</u>	<u>63</u>	<u>66</u>	<u>63</u>	<u>40</u>	<u>35</u>	<u>41</u>	<u>30</u>	<u>1.41</u>
Subtotal on Lesser Zab	70	83	125	125	110	161	171	160	96	87	109	79	3.62
Greater Zab River^{2/}													
Makhmour Project, Including Eski Kelek	6	12	23	20	17	36	35	33	13	11	21	9	.62
Khazir River^{2/}													
Gomel and Khazir-Gomel Projects	<u>-2</u>	<u>-1</u>	<u>3</u>	<u>15</u>	<u>23</u>	<u>35</u>	<u>38</u>	<u>34</u>	<u>24</u>	<u>19</u>	<u>3</u>	<u>0</u>	<u>.50</u>
SYSTEM TOTAL for Irrigation	686	934	1368	1517	1316	1858	1929	1795	1292	1067	1000	719	40.73

^{1/} Losses on feeder canals to Nahrwan and Adhaim projects included.

^{2/} Net requirements for projects on Tigris above Fatha and on Greater Zab, Lesser Zab, and Khazir rivers after allowing for return flows.

^{3/} Jazira Project can be irrigated only if Eski Mosul Reservoir is included in system.

Jazira Project

5.49 Tables 5.2 and 5.3 show irrigation requirements with the Jazira Project above Eski Mosul damsite. The Jazira Project is considered by Kuljian Corporation, consultant on the project, to be not feasible unless Eski Mosul Dam is constructed. Therefore, operation studies not including Eski Mosul did not allow for Jazira diversion requirements. On the other hand, for systems that did include Eski Mosul, studies were made both with and without the Jazira Project because Jazira diversion imposes a high dead storage level on Eski Mosul Reservoir (for reasons of command) and thereby reduces reservoir yield.

Navigation Requirements

5.50 Requirements for navigation below Kut were considered in some of the operation studies. The total required flow past Kut to meet navigation needs is also included in Tables 5.2 and 5.3.

Tolerable Shortages

5.51 There are several ways in which stored water can be used for irrigation, the choice usually depending on such factors as land ownership, distributary canal networks, types of crops, social, organization, etc. If the irrigable land should greatly exceed that which could be irrigated by the average water supply, if the distributary network could handle excessive flows, and if the irrigated area could fluctuate greatly from year to year without causing economic and social hardships, then all water stored during each flood season could be used in the following low-river season without holding over any storage for the benefit of subsequent years. This method of operation would result in the maximum usage of water. The other extreme would be to develop

only the amount of irrigated land that could always be supplied with its full water requirements. The latter method would result in greater cost of storage facilities per unit of land irrigated and in large waste of water during most years. Such operation is rarely economical and is seldom practiced.

5.52 The problem of degree and season of shortage of irrigation water that could be tolerated is a social and economic question outside our terms of reference. However, it was necessary to make assumptions and to use these assumptions consistently throughout the operation studies. The assumptions were:

- a. No shortages in irrigation requirements would be permitted during the period from November to May inclusive.
- b. Shortages of 20 percent in summer irrigation requirements (June to October inclusive) could be tolerated in a limited number of years.
- c. In four years of the eight-year basic study period, June 1929 through May 1937, that is, in half of the summers, the 20-percent shortage could be tolerated.

5.53 One reason for considering summer rather than winter shortages to be tolerable was because subsistence crops are normally grown in the winter. A more important reason, however, was that this method of operation resulted in less waste of the available water supply, since a reliable index is available to determine whether or not a summer shortage should be scheduled. The index used was a combination of content in system reservoirs on May 31 and reservoir inflows during the month of May. Flows during May are a good indication of

future flows during the summer recession period, which, together with the content in system reservoirs, govern the ability of a system to maintain a certain firm yield, subject to tolerable shortages. On the other hand, there is no reliable index to determine whether a winter shortage should be scheduled, since the flows at the start of this season (November) bear no relation to the total flow during the entire winter season, particularly during the flood months of February through April. Thus, it could easily happen that a winter shortage would be established under conditions in which the subsequent river flows made it unnecessary to do so, leading to possible waste of water.

5.54 It may be said that May 31 is too late a date for giving notice of a summer shortage. In practice, the nature of the flood season would be known by the middle of April at latest, and both reservoir content on May 31 and May flows could be forecast fairly closely. This subject is discussed further in Chapter 8.

5.55 The assumptions as to tolerable shortages result in annual irrigation deliveries during a summer shortage year of approximately 90 percent of the firm irrigation yield. Likewise, the average deliveries during the eight-year basic study period are approximately 95 percent of the firm irrigation yield.

System Spills

5.56 System spills include all water considered unusable for meeting irrigation requirements (paragraph 5.32) and also that portion of the usable water which flows out of the system unused. This latter water consists of two categories:

- a. Uncontrolled runoff which occurs below reservoirs in amounts that are in excess of irrigation requirements. For example, in systems not including Fatha or Wadi Tharthar, there are sometimes large uncontrolled inflows below the upstream reservoirs.
- b. Inflows to reservoirs that cannot be controlled by the reservoirs, under the adopted rule curves, to prevent reservoir releases in excess of irrigation requirements.

5.57 The flood-control rule curves discussed in paragraph 5.63 were strictly adhered to in the reservoir operations, without any "hindsight" as to whether the size of the subsequent flood did indeed necessitate that reservoirs be drawn down previously in order to provide flood storage. In some cases this resulted in water being spilled from reservoirs during the early months of a year, whereas the later actual flood was insufficient to fill the reservoir again. However, this situation arose during the basic study period only in the case of Wadi Tharthar Reservoir in 1929 and early 1930. In practice it is likely that snow surveys and other data for seasonal streamflow forecasting would enable such loss of water to be avoided or reduced. However, for the purpose of the operation studies, this was not allowed.

5.58 It should not be thought that all water designated as system spills would serve no useful purpose. Some would be of benefit to rice cultivation through flooding (as long as that system of cultivation remains), to marsh dwellers in southern Iraq in sustaining their fishing livelihood, to maintain reed growth for projected paper factories and domestic use, and to reduce salt water encroachment in the Shatt-el-Arab, where salt water could adversely affect irrigation.

Evaporation Losses

5.59 Evaporation from each reservoir was computed on the basis of an assumed loss of 2.0 meters annually, distributed by months as estimated in the Haigh Commission Report. The Haigh Commission assumed an evaporation loss of 2.5 meters for Wadi Tharthar and Fatha reservoirs and 2.0 meters for other projected reservoirs in the Tigris River Basin. Preliminary information from Nedeco (the consultant investigating the use of Wadi Tharthar Reservoir for irrigation) indicates that an annual loss of 2.0 meters is considered appropriate for that reservoir. The same value can reasonably be used for Fatha. The annual loss at upstream reservoirs is undoubtedly less, but the data available at the start of the studies were inadequate to establish the proper amount. In addition, the total evaporation loss from upstream reservoirs is relatively small, and a change from the 2.0-meter loss for those reservoirs would have a small effect on the results. The evaporation loss was computed on the basis of reservoir content at the first of each month.

Other Basic Data and Operating Criteria

Reservoir Data

5.60 The volume curves for various reservoirs are shown on Exhibit 21, which includes a documentation of the sources of data. The reservoir data used for estimates of evaporation losses and the reservoir outlet capacities are from the same sources.

5.61 The alternative heights of dam considered for the various reservoirs are also given on Exhibit 21 and on Tables 5.1 and 5.6. For

Table 5.6

RULE CURVES USED IN IRRIGATION OPERATION STUDIES

(Values Represent Total of Dead Storage and Maximum Allowable Irrigation Storage.)

Reservoir	Normal Maximum Operating Level (meters m. s. l.)	End-of-Month Content in Millions of Cubic Meters											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Derbend-i-Khan	485	2.50	2.50	2.50	2.74	3.00	3.00	3.00	3.00	3.00	3.00	2.74	2.50
Dokan	511	5.32	5.32	5.87	6.58	6.89	6.89	6.89	6.89	5.97	5.32	5.32	5.32
Bekhne	550	6.32	6.32	6.32	7.32	8.32	8.32	8.32	8.32	7.92	7.50	7.10	6.71
530	3.79	3.79	3.79	3.79	4.79	5.79	5.79	5.79	5.79	5.39	4.97	4.58	4.18
500	0.97	0.97	0.97	0.97	1.97	2.97	2.97	2.97	2.97	2.58	2.16	1.76	1.37
Eski Mosul	335	10.40	10.40	10.40	11.78	13.16	13.16	13.16	13.16	12.61	12.06	11.50	10.96
328	7.51	7.51	7.51	8.89	10.26	10.26	10.26	10.26	10.26	9.71	9.16	8.61	7.99
320	4.88	4.88	4.88	6.26	7.63	7.63	7.63	7.63	7.63	7.08	6.53	5.98	5.43
Fatha	^{1/} 178 ^{2/} 178 ^{3/} 178	19.0	19.0	19.0	21.5	24.0	24.0	24.0	24.0	23.0	22.0	21.0	20.0
	178 ^{1/} 178 ^{2/} 178 ^{3/} 178	21.0	21.0	21.0	22.5	24.0	24.0	24.0	24.0	23.4	22.8	22.2	21.6
	172.5 ^{1/} 172.5 ^{2/} 172.5 ^{3/} 172.5	23.0	23.0	23.0	23.5	24.0	24.0	24.0	24.0	23.8	23.6	23.4	23.2
	172.5 ^{1/} 172.5 ^{2/} 172.5 ^{3/} 172.5	13.0	13.0	13.0	15.5	18.0	18.0	18.0	18.0	17.0	16.0	15.0	14.0
	15.0	15.0	15.0	15.0	16.5	18.0	18.0	18.0	18.0	17.4	16.8	16.2	15.6
	17.0	17.0	17.0	17.0	17.5	18.0	18.0	18.0	18.0	17.8	17.6	17.3	17.2
	165 ^{1/} 165 ^{2/} 165 ^{3/} 165	6.8	6.8	6.8	9.3	11.8	11.8	11.8	11.8	10.8	9.8	8.8	7.8
	165 ^{1/} 165 ^{2/} 165 ^{3/} 165	8.8	8.8	8.8	10.3	11.8	11.8	11.8	11.8	11.2	10.6	10.0	9.4
	165 ^{1/} 165 ^{2/} 165 ^{3/} 165	10.8	10.8	10.8	11.3	11.8	11.8	11.8	11.8	11.6	11.4	11.2	11.0
Wadi Tharthar	^{4/} 59	55.3	53.8	52.3	59.9	67.4	65.9	64.4	62.9	61.4	59.9	58.3	56.8

^{1/} With Derbend-i-Khan and Dokan.^{2/} With Derbend-i-Khan, Dokan, and one other reservoir upstream from Fatha.^{3/} With Derbend-i-Khan, Dokan, and two other reservoirs upstream from Fatha.^{4/} Same rule curve applies to all Wadi Tharthar studies, regardless of outlet elevation.

Dokan and Derbend-i-Khan reservoirs, only one height of dam was considered, that to which the dam was constructed. Alternative possibilities were considered for Bekhme, Eski Mosul, and Fatha reservoirs, most of which had been considered by other consultants. Three levels of irrigation outlet were studied at Wadi Tharthar, two of which have been studied by Nedeco. Wadi Tharthar outlet capacity was considered to be 800 cumecs to provide a reasonable balance between irrigation and flood-control requirements. With four- or five-reservoir systems, 600 cumecs might suffice.

5.62 It was assumed in the reservoir operation studies that adequate outlet capacity to meet irrigation requirements would be provided at Dokan Dam by fitting valves to the existing penstocks if a power plant is not built.

Rule Curves

5.63 The flood rule curves used in the irrigation operation studies were somewhat different for some reservoirs from those used in the flood-control studies. The rule curves for the flood-control studies are shown on Exhibit 21, while the rule curves for the irrigation studies are given in Table 5.6. The rule curves for both sets of studies were the same for Derbend-i-Khan, Dokan, and Bekhme, and for low dams at Eski Mosul and Fatha. For intermediate and high dams at Eski Mosul and Fatha, the rule curve elevations adopted for the irrigation studies were somewhat higher than for the flood-control studies. It was considered that a very modest degree of forecasting would enable such a concession to the needs of irrigation storage to be made with safety.

5.64 The difference in rule curves for certain reservoirs resulted in inconsistencies (as between the flood-control and irrigation studies) in reservoir performance for only the relatively unimportant higher flow periods after the end of the basic study period upon which the capability

of reservoir systems was assessed. For most systems there would have been no reduction in firm irrigation yield if the lower rule curves (adopted for flood control) had been used for the irrigation studies, since the reservoirs had been drawn below that rule curve elevation during the critical period. This was not the case in a few instances, but the difference in rule curve elevation would have had only a very slight effect on the quoted yields.

5.65 The rule curve adopted for Wadi Tharthar, when used for irrigation storage, took into consideration its limited outlet capacity and the necessity to provide sufficient space for flood-control storage at an early stage in the flood season. Upstream reservoirs could thus always be lowered and excess volumes safely diverted to Tharthar in the event of a large flood's being forecast. Unlike the case of Fatha Reservoir, the same rule curve was used regardless of which upstream reservoirs were in the system since these alternatives, which influence the flood peaks, would make little difference to flood volumes that had to be controlled. No system studied included both Fatha and Wadi Tharthar for irrigation storage.

Link Canals

5.66 A link canal was assumed in all studies to be available for importing water from the Lesser Zab to the Diyala River projects. It is understood that construction of this link is provided for, should it be found necessary, in current projects and that it presents no particular physical difficulties. In the operation studies the capacity of the link varied between (30) and (55) cumecs, and it was operated according to a specified parameter which related content of Dokan Reservoir to that of

Derbend-i-Khan. As is explained later under "Results of Irrigation Studies," in paragraphs 5.88-5.89, the Lesser Zab-Diyala Link was found to be necessary to eliminate unscheduled shortages in the Diyala area.

5.67 Another link canal between the Greater and Lesser Zab rivers was assumed in studies of systems with large storage capacity and high yield. At the time of the studies this link was a feasible proposition because of the projected Makhmour and Batmah barrage developments. After the studies were completed these plans were changed, and the link became no longer practicable. However, it appears possible to achieve the same object (import of water to the Lesser Zab and Diyala River projects) by means of a diversion from the Tigris in the Fatha-Samarra reach, where a link canal could be taken to the Adhaim River diversion works. This would relieve the load upon Lesser Zab water resources, making more water available for transfer to the Diyala River projects. The link from the Tigris could be further extended to the Diyala should that ever be found necessary.

5.68 These link canals played an important part in the operation studies, especially the Lesser Zab-Diyala Link, since in the conception of the studies all projects received at the same time the same percentage of their irrigation requirements. Thus, flexibility in use of water resources was necessary in order to avoid the situation in which an unscheduled storage in one project area (which was always that on the Diyala) would govern the firm irrigation yield of a whole system.

Phasing of Reservoirs

5.69 The computer program was designed for the reservoirs (except Wadi Tharthar) in each system to be kept "in phase." This means that

reservoirs were kept equally "filled," where the "fullness" is defined as the ratio of the contents of a reservoir to its rule curve contents. The subject is fully described in Appendix D, paragraph 2.43-2.45. Phasing of the reservoirs results in their more efficient use because the maximum chance is thereby given that each reservoir will take its full part in both flood-control and irrigation storage.

5.70 An exception to the phasing procedure was Wadi Tharthar Reservoir, which was operated for large drawdown as soon as upstream reservoirs were drawn down to rule curve levels. This was done because of the heavy evaporation loss from Wadi Tharthar and the need to reduce its evaporation area whenever possible.

Results of Irrigation Studies

Presentation of Results

5.71 The summarized results of the irrigation operation studies are presented in Table 5.1. This table gives for each system of reservoirs the annual delivery of irrigation water (not including any deduction for tolerable shortages) that could have been ensured during the basic study period from 1929 to 1937. This delivery has been defined as the "firm irrigation yield" of the particular system. The firm irrigation yield determines the level of irrigation development that the system could sustain, provided development followed the 1975 or 1985 pattern of irrigation requirements with respect to distribution by months and project areas. The same information is presented in graphical form on Exhibit 23, which relates firm irrigation yields to total active reservoir storage capacities.

5.72 An index of the extent to which the resources of the Tigris River system can be utilized by the various schemes is given by comparing the firm irrigation yield with the available water supply. For this purpose, the water supply is expressed as "gross" (sum of recorded flows of the Tigris at Baghdad and the Diyala at Discharge Site) and as "usable" (the gross supply less the flows of the Adhaim and Lower Diyala, which are considered unusable for meeting irrigation requirements). The average gross supply for the 27-year period of October 1929 through September 1956 was 43.5 milliards, while the average usable supply was 41.9 milliards. For the eight-year basic study period these quantities were 34.4 and 33.0 milliards, respectively. The driest water year was 1929-30, when the gross supply was 20.9 milliards and the usable supply 19.9 milliards.

5.73 Table 5.1 also shows the amounts of any net reduction in content of reservoirs in each system over the eight-year basic study period. Obviously, it was only because of this reduction that the larger systems were able to deliver amounts of water for irrigation in excess of the average discharge of the Tigris River system during the eight-year period. The amounts delivered were approximately 95 percent of the firm irrigation yields, as explained in paragraph 5.55.

5.74 Amounts of evaporation losses and of system spills also are presented in Table 5.1 and are shown in graphical form on Exhibit 24. The amounts shown were the average during the basic study period of 1929 through 1937. The amount of system spills obviously varied greatly during each of the eight years. During extended periods of average river flows, the amounts of system spills were substantially greater than during the basic study period. Evaporation losses were also greater during

periods of average or better river flows because reservoirs were then more nearly full and had larger areas exposed to evaporation. However, evaporation losses did not have the same range of variation as the amounts of system spills.

5.75 Exhibits 26, 27, and 28 show typical irrigation operation studies in diagrammatic form. These typical studies are for the existing system of Dokan and Derbend-i-Khan, the existing system plus a low Eski Mosul, and the existing system plus a high Eski Mosul and a high Bekhme. These studies are shown for illustrative purposes only and do not imply any preference in systems.

Comparison of Firm Irrigation Yields

5.76 The operation studies were carried out under certain assumptions, which were discussed earlier. Therefore, the results and conclusions arrived at are valid only for the particular conditions assumed. The order of the systems when arranged according to magnitude of the firm irrigation yield could change if the assumed conditions were changed greatly. Nevertheless, we are of the opinion that such significant changes are unlikely and that the results can be considered indicative of the relative value of the different systems for irrigation purposes. The effect of the assumptions upon the results obtained is discussed later in this chapter.

5.77 The highest firm irrigation yield attained in any of the studies was 38.0 milliards. This yield resulted from a combination of Dokan, Derbend-i-Khan, a high Eski Mosul, a high Bekhme, and a large use of Wadi Tharthar for irrigation (outlet level 35 meters).

5.78 The existing system of Dokan and Derbend-i-Khan was found to have a firm irrigation yield of 23.1 milliards. As storage is added to the existing system the firm irrigation yield increases, but the rate of increase

drops with each increment in storage capacity. This is demonstrated graphically on Exhibit 23. A short operation study was worked by hand to determine the firm irrigation yield from natural flow without any reservoirs. This study was worked using 1975 irrigation requirements to make it as nearly comparable as possible with Study No. 20(b) for the existing two-reservoir system. Without any reservoirs, shortages developed every year, thereby substantially reducing the yield. The minimum yield was 15.6 milliards in the year June 1930 through May 1931. If a 20-percent tolerable summer shortage had been assumed for that year, the "firm irrigation" yield would have been 17.3 milliards.

5.79 Inclusion of the Jazira Project caused a substantial reduction in the firm irrigation yield from reservoir systems including Eski Mosul because of the required high dead storage. The reduction amounted to about one and a half to two milliards in the three-reservoir systems of Dokan, Derbend-i-Khan, and Eski Mosul, with Eski Mosul at either its high, intermediate, or low level. The reduction was somewhat smaller in systems involving four or five reservoirs in which Eski Mosul was one of the reservoirs.

Comparison of Spills and Evaporation Losses

5.80 With the existing system, a large annual system spill, originating from the uncontrolled parts of the basin, occurred during the basic study period. The amount of system spill decreased rapidly as additional storage was provided on the presently uncontrolled rivers. The average annual system spill of usable resources during the critical period was less than 1.0 milliards for all systems of over 22 milliards of active storage. All systems including Wadi Tharthar for irrigation showed somewhat greater system spill than for "onstream" reservoirs of comparable storage.

5.81 The average annual evaporation loss during the basic study period was significantly higher for systems including Wadi Tharthar for irrigation storage. In general, such systems lost approximately 1.5 milliards more of annual evaporation than those systems of comparable storage capacity which included Fatha Reservoir. Similarly, systems including a high Fatha Reservoir with Dokan and Derbend-i-Khan reservoirs or a lower Fatha Reservoir with either Bekhme or Eski Mosul added to these reservoirs lost 0.5 to 1.2 milliards more than systems of comparable storage capacity which consisted only of upstream reservoirs.

5.82 The estimates of evaporation losses are informative but should be used with caution as the results can be misleading. It is true that systems involving Wadi Tharthar irrigation storage have substantially less firm irrigation yield for a given amount of storage, resulting primarily from increased evaporation losses. However, as far as the Tigris irrigation projects listed in Tables 5.2 and 5.3 are concerned (which do not include lower Iraq), this increased evaporation loss can be compensated for by substantial increases in usable Wadi Tharthar storage capacity. Thus, for these projects, it becomes a matter of economics as to whether the provision of additional storage at Wadi Tharthar gives a greater value for the capital expenditure incurred than provision of lesser amounts of upstream storage which produce the same firm irrigation yield.

5.83 Nevertheless, it cannot be denied that systems involving greater evaporation losses involve a greater permanent non-beneficial use of water, that is, smaller system spills. This is not of importance to the Tigris irrigation projects if an equal firm system yield can be provided by an increase in storage capacity. However, it is of importance to lower Iraq, which will ultimately be dependent in large part on Tigris spills, as discussed in paragraph 5.58.

5.84 It must also be remembered that though the system spills from the larger reservoir systems, as shown in Table 5.1, differ very little, the spills in a period of average flows would differ to a greater extent. For example, a system including as the only additional reservoir the low-level-outlet Wadi Tharthar would have an average annual spill of some 0.7 milliards less than a system including the high Eski Mosul (without the Jazira Project), with each system providing practically the same firm irrigation yield. This greater spill from the system with Eski Mosul could be of substantial benefit to lower Iraq.

Effect of Flood Rule Curves

5.85 The seasonal flood-control reservations did not reduce the irrigation deliveries during the basic study period in any systems except those that included use of Wadi Tharthar Reservoir for irrigation storage. As previously stated, these reservations resulted also in Wadi Tharthar's being the only reservoir that could not be full at the beginning of the basic study period. Therefore, the conflicting requirements of irrigation and flood control materially reduce the irrigation benefits that could be obtained from Wadi Tharthar for irrigation storage.

Effect of Order of Construction of Reservoirs

5.86 Exhibit 23 shows the effect of variation in the order of construction of the reservoirs that were considered. The exhibit illustrates the principle that the smaller the system to which a particular reservoir is added the greater will be the benefits from it. With a small capacity the storage space is more likely to refill and be fully used each year. With a large capacity there may be long periods during the critical period when the storage does not refill; hence the benefits from the storage are spread

out over several years rather than being repeated each year. As an example, if the High Bekhme Dam were added to the existing system it would increase the firm irrigation yield by 7.9 milliards, while if it were added to a system that already included the high Eski Mosul Dam (with the Jazira Project), it would increase the yield by only 3.0 milliards.

5.87 The above principle must be carefully considered in all river basin planning since it directly affects the optimum development of the basin. It might be found that the benefits from a particular system would exceed the costs, but that the benefits from the last increment would be less than the cost of providing that increment. Therefore, the last increment could not be justified from purely economic considerations.

Studies of Link Canals

5.88 Study 20(b) of the existing reservoir system, which gave a firm irrigation yield slightly greater than 1975 requirements, demonstrated the benefits of the Lesser Zab-Diyala Link. Without the link there would have been deficiencies in the Diyala areas in excess of tolerable shortages. The deficiencies would have been 0.25 milliards in 1931 and 0.50 milliards in 1937, or about 7 percent and 14 percent, respectively, of the annual requirements. There would have been another deficiency of 0.64 milliards, or 18 percent of annual requirements, in 1948. As the firm yield of the larger reservoir systems increased, the Lesser Zab-Diyala Link became even more necessary.

5.89 Import of water to the Lesser Zab-Diyala complex became necessary when the annual requirements (without tolerable shortages)

of its projects reached approximately 103 percent of 1985 requirements. A link canal was then provided in the operation studies, but its real necessity at that late stage of development cannot be determined until additional data on the water resources and irrigation requirements of the Lesser Zab and Diyala areas become available.

Adequacy of Dokan Outlet Capacity

5.90 The capacity of the present three outlets at Dokan Dam (consisting of a valved penstock and two irrigation valves) is not entirely adequate for meeting requirements. For the firm yield of the existing system given by Study 20(b), the capacity was sufficient for all but twelve months of the eight-year period, while with one additional valved penstock it would be sufficient for all but two of the months. For the period of June 1937 through May 1956, the present capacity would have sufficed in all but nine months, and with one additional valved penstock, in all but two months. The existence of a Lesser Zab-Diyala Link Canal did not significantly affect outlet requirements at Dokan.

5.91 Study 17(c), which includes a minimum flow of 325 cumecs below Kut for navigation, gives results that are somewhat similar. The existing capacity would have resulted in outlet deficiencies in about 15 months, and another valved penstock would have reduced these deficiencies to about four months.

5.92 The two studies indicate that shortages due to insufficient outlet capacity at Dokan would occur a small percent of the time in meeting 1975 irrigation requirements with the existing reservoir system, provided one further valved penstock were installed. If a power plant were installed, there would of course be ample capacity to meet requirements at all stages of development.

5.93 Two special studies were made of the time for initial filling of Wadi Tharthar Reservoir, assuming it would be used for irrigation. These studies were made to determine the time required to bring the reservoir level to the 35-meter command level at the outlet channel and also to the flood-control rule curve level. In the first study, 1975 irrigation requirements were assumed, with a minimum flow of 150 cumecs past Samarra. In the second study the assumptions were 80 percent of 1975 irrigation requirements and a minimum flow of 500 cumecs past Samarra. Rice flooding requirements were not considered in either study.

5.94 It was assumed in both studies that streamflows would follow the chronological occurrence of past streamflows, with filling of Wadi Tharthar starting at various dates. The results, shown in Table 5.7, indicate that the filling time to the 35-meter level can be expected to vary between five and 49 months, depending primarily on the runoff conditions that occur during filling. The filling periods would be increased over those shown in Table 5.7 if navigation requirements were met; an even greater increase would occur if rice flooding requirements were met.

Salinity Control of Wadi Tharthar Water

5.95 It is known that on the first filling of Wadi Tharthar much salt would be leached out of the sides of the reservoir. Preliminary information from Nedeco indicates that this salt would probably be sufficiently diluted during filling of the reservoir for the water to be reasonably usable for irrigation; however, the time required for filling would affect its salinity.

Table 5.7

INITIAL FILLING OF WADI THARTHAR RESERVOIR

Historical Date Corresponding to <u>Start of Filling</u>	<u>Filled to Elevation 35 m.</u>		<u>Filled to Flood-Control Rule Curve Level</u>		
	<u>Date</u>	<u>Number of Months</u>	<u>Date</u>	<u>Number of Months</u>	
A. <u>With 1975 Irrigation Requirements and Minimum Flow Past Samarra of 150 Cubic Meters per Second</u>					
1 June 1929	May	1933	48	February 1937	93
1 January 1935	April	1937	28	December 1938	48
1 January 1940	May	1940	5	January 1942	25
1 January 1945	April	1946	16	January 1949	49
1 January 1950	April	1952	28	January 1954	49
B. <u>With 80% of 1975 Irrigation Requirements and Minimum Flow Past Samarra of 500 Cubic Meters per Second</u>					
1 June 1929	June	1933	49	December 1936	91
1 January 1935	March	1937	27	January 1939	49
1 January 1940	December	1940	12	May 1941	17
1 January 1945	April	1946	16	February 1948	38
1 January 1950	April	1952	28	October 1953	46

5.96 Subsequent operation of Wadi Tharthar would have to be carried out to keep the salt content of the water at an acceptable level. The salt content could be held to a minimum by diverting at Samarra the maximum possible flow through Wadi Tharthar and passing it back to the river again, instead of passing such flows directly down the river at Samarra. This would, of course, result in minimum power development at Samarra Barrage.

5.97 Evaporation losses from Wadi Tharthar were reduced in the operation studies (paragraph 5.70) by drawing down this reservoir first. This procedure resulted in the reservoir's being drawn down below outlet level whenever another reservoir, additional to the existing system, was also included. Wadi Tharthar was below outlet level without any inflows for a period of several years between 1932 and 1937 in some of the studies. Salinity would then of course increase.

5.98 It must be concluded that use of Wadi Tharthar storage water would require careful operations with regard to salinity and that its usage for irrigation might not always be safe.

Validity of Results

5.99 In paragraph 5.10 we listed a number of assumptions that were inherent in the irrigation operation studies, and we indicated that the results are valid only for the conditions corresponding to these assumptions. The remainder of this chapter is devoted to an examination of these assumptions and an appraisal of the effect the assumptions have on the validity of the results.

Severity of Critical Period

5.100 Assumption (a) in paragraph 5.10 was that the basic study period is suitable as a basis for design. This was the most important assumption in these studies, as is generally true in all studies of this type. The use of the historical minimum flow period as the basis for design is a widely accepted procedure and is often accepted without question. Nevertheless, an examination of the degree of severity of the basic study period and its suitability for design purposes is very much in order.

5.101 We stated in paragraph 5.25 that the basic study period probably was the most severe of any period occurring in the past 57 years, but that its average flow was only about five percent lower than the flow which occurred during the water years 1958-62. In addition, comparison of the lowest year (1929-30) with other years indicates that that year was not extremely unusual in its severity; the flow at Baghdad in 1929-30 is recorded as 17.5 milliards, compared with 19.9 milliards in 1924-25 and 22.1 milliards in 1954-55. Therefore, the basic study period was not exceptionally severe in the 57 years of reasonably reliable history. A period of 57 years is a comparatively short period on which to base developments expected to serve Iraq for several centuries, and this short period could have had exceptional features not likely to occur in a future period of comparable length.

5.102 There are three aspects of streamflow that affect the design and operation of a reservoir system. These are (a) the mean flow of the river, (b) the sequence of flow events, and (c) the variability of flow events.

5.103 The long-term mean annual flow of a river can be established only after centuries of record, since on many rivers there seems to be a tendency for high and low values to be grouped together. Mean flows for periods of 30 to 50 years have shown deviations of 10 to 15 percent from the long-term mean in several rivers having long periods of record, such as the Nile, Thames, and Mississippi. In such cases, the long-term mean annual flow would have had little weight in design of a reservoir system since certainly the 30 to 50 years of lower flows would have been of more importance for reservoir design.

5.104 Shorter-term grouping can be detected in the flows of the Tigris River. Although early records during the 1906-62 period are very approximate, the entire period is suitable for this sort of analysis. The grouping tendency is shown on Table 5.8, but this of course gives no indication as to how the 1906-62 period compares with the average through several centuries. It can only be said that there is such a miscellaneous assortment of high and low groups that there is no reason to suspect that the mean flow during the period had an exceptional deviation from the long-term mean.

5.105 An analysis of annual flows on a frequency basis to evaluate the degree of severity of the basic period used in our studies would serve no useful purpose. The philosophy of our studies involved use of hold-over storage, and in such cases frequencies of individual annual flows are of minor importance. The sequential grouping of a number of low annual events becomes paramount in such cases.

5.106 Hurst^{1/} has analyzed a large variety of natural phenomena (river discharges, rainfalls, temperatures, tree rings, sediment deposits,

^{1/} H. E. Hurst, "Long-Term Storage Capacity of Reservoirs," Transactions, American Society of Civil Engineers, vol. 116 (1951), p.770.

H. E. Hurst, "Methods of Using Long-Term Storage in Reservoirs," Proceedings of the Institution of Civil Engineers, September 1956, p. 519.

Table 5.8

GROUPING OF TIGRIS ANNUAL FLOWS

<u>Period</u>	<u>No. of Years</u>	Period mean as approx. percent of <u>"average"</u>	<u>Remarks</u>
1906-1910	5	150 (very approx.)	1906 and 1907 were very high years as recorded and as attested by old inhabitants, almost certainly higher than any subsequent years to date.
1911-1923	13	100 (approx.)	Mixture of fairly average years.
1924-1937	14	80	Mostly low years with 1930 very low and only two high years, 1926 and 1929.
1938-1943	6	130	Consistently high years.
1944-1957	14	105	Mixture of fairly average years with two high years, 1946 and 1954.
1958-1962	5	75	Consistently low years.

etc.) in which variations of groupings from the mean were examined. Although there is not complete agreement that Hurst's findings are applicable to annual river flows, his concept has been accepted by many leading hydrologic engineers. We believe that his results can be used to assist in the evaluation of the degree of severity of the basic study period for the Tigris River.

5.107 Hurst derived an equation which gave a measure of the sequence and variation of a group of annual values. A factor K in his equation gives a general indication of the degree of variation of groups from the mean. In analyzing 690 cases with periods ranging from 30 to 2000 years, he obtained a mean value of K of 0.73, with extreme values of 0.46 and 0.96.

5.108 We have analyzed flows of the Tigris Basin according to the Hurst procedure. Annual flows at Baghdad, Fatha, Mosul, Eski Kelek, Altun Kupri, and Diyala Discharge Site were analyzed for the 1930-61 period. Values of K of 0.78, 0.84, 0.84, 0.83, 0.76, and 0.67, respectively, were obtained. In addition a value of 0.64 was obtained for the Baghdad flows of 1907-1929, some of which were admittedly of poor accuracy.

5.109 There are no serious discrepancies between the K values for the Tigris Basin and those obtained by Hurst. The variations we obtained are well within the range he found for a far greater sampling of natural phenomena, and the average (weighed according to period of record, including Baghdad flows for 1907-29) is 0.77, compared with Hurst's average of 0.73. We conclude that application of the Hurst theory reveals no reason to suspect that the annual flows of the Tigris during the 1930-61 period have been exceptional in sequence or variability.

We conclude, further, that the basic study period is suitable as a basis for design.

Priority of Water Use

5.110 Assumptions (b) and (c) combine to define the priority of use of water. Irrigation was given exclusive priority in the irrigation studies, except at Wadi Tharthar, where moderate concessions were made to flood control. This assumption hardly seems controversial, particularly the priority of irrigation over flood control, since water for irrigation is an irreplaceable resource, while additional flood control can be gained by construction of additional storage or diversion works. Minor concessions to power may be arguable, but this is a policy decision; the results of the irrigation and power studies afford a basis for these decisions.

5.111 The rule curves that were used are in conformity with the priority of irrigation, since they have as their basis provision of flood-control space in such a manner that irrigation will not be adversely affected. As actual operating experience is accumulated, it can be expected that the rule curves will be modified to obtain the full benefits of forecasting procedures that may be developed from the snow surveys and other data whose collection was initiated by the Hydrological Survey. However, the modification of rule curves would not affect the firm irrigation yields since there were no spills during the critical period that could have been conserved by use of forecasting procedures, except in the case of Wadi Tharthar.

Irrigation Requirements

5.112 Assumptions (d) and (e) in paragraph 5.10 are concerned with pattern, magnitude, and tolerable shortages in irrigation requirements.

These assumptions normally would be expected to have an appreciable effect on the results and are discussed separately in the following paragraphs.

5.113 The pattern of irrigation requirements, that is, the distribution by seasons and months, can be expected to have some effect on the firm irrigation yield, but probably will have little effect on the relative merits of alternative systems. A higher summer use of water could be expected to result in a lesser requirement for system storage to provide the same total annual irrigation yield because (a) the water use conforms more nearly to the annual pattern of natural flows and (b) there is less need to hold water over for winter use and consequently lower evaporation losses. The magnitude of such effects has not been investigated, but we believe they are relatively unimportant in terms of the primary purpose of the studies, that is, in the comparison of alternative systems.

5.114 The assumed magnitudes of irrigation requirements have no effect on the relative merits of the various systems. The distribution of the requirements between project areas is important if there are not sufficient links to provide flexibility in distribution of available water, but it is unimportant if the links are provided, as is the case in assumptions (j) and (k).

5.115 The assumed level for tolerable shortage has an obvious effect on the results of the study. As discussed in paragraph 5.51-5.54, the decision on the shortage to be accepted is a policy decision, obviously not available until after presentation of these studies. In the absence of such a policy decision, the assumption has been based on practice in other areas and judgment as to what would be equitable for Iraq. If

different levels for a tolerable shortage are decided upon, qualitative evaluations of the effects on firm irrigation yield can be made. However, the relative merits of alternative systems would not be changed.

Basic Data

5.116 Assumption (f) is concerned with the validity of basic data on reservoir capacities, streamflow, and evaporation. Of these, the possible error in evaporation, in proportion to the total resources of the system, is minor and cannot significantly affect the results. Significant errors in reservoir capacity or streamflow could affect the results appreciably.

5.117 The reservoir data are believed to be reasonably reliable as far as visual storage is concerned. However, at some of the reservoirs there may be appreciable bank storage, which is storage capacity in underground areas immediately adjoining the reservoir that is useful on an annual basis in the same manner as the visual surface storage. Water may enter these bank storages as the reservoir rises and be evacuated as the reservoir is lowered.

5.118 The availability of bank storage is not uncommon in large reservoirs, particularly in cavernous limestone areas. It is reported to be already apparent at Dokan Reservoir, with preliminary analyses indicating that such storage may be 10 to 15 percent of the visual storage. Bank storage also can be expected to be large at Bekhme, but probably will be negligible at all other reservoirs.

5.119 The availability of bank storage would increase the firm irrigation yield by providing more usable storage. The presence of bank storage at Bekhme and its relative absence at Eski Mosul, Fatha, and

Wadi Tharthar would increase the value of Bekhme as compared with the other reservoirs. This increase in value of Bekhme could be deduced, after the extent of bank storage at Bekhme had been estimated, by using a curve drawn through the plotted points of Exhibit 23.

5.120 The streamflow data and estimates used in the studies are believed to be reasonably reliable for the purpose intended. Estimates based on correlations were necessary for inflows to Bekhme, Dokan, and Derbend-i-Khan. After completion of the studies, additional data at Dokan and Derbend-i-Khan became available which indicated that the inflow estimates may have been somewhat too high in the winter months; by analogy the Bekhme estimates also may have been too high. This would have the effect of a modest lowering of the firm irrigation yield of the existing system and of systems including Bekhme Reservoir. However, any difference in yield due to this cause would not affect the relative merits of alternative systems.

Water Resources

5.121 Assumption (g) in paragraph 5.10, as to the Baghdad record's representing the historical water resources of the Tigris River system without the Diyala tributary, is admittedly not correct when breaches occurred upstream of Baghdad. However, the Baghdad record was not thus affected during the historical period upon which the results of our irrigation studies were based. There is no doubt that the Baghdad record is the most reliable in normal conditions.

5.122 The adjustments in which apparent historical losses between Fatha and Baghdad were reduced to take account of future river control by upstream reservoirs were somewhat arbitrarily estimated. Different estimates could be made by different methods, but our judgment that

Fatha and Eski Mosul reservoirs would give the greatest degree of control, and hence the greatest relative reduction in losses, is scarcely disputable. Further streamflow data and analysis should lead to better assessments of the Tigris River regime under future conditions, but we do not consider that the relative results of alternative reservoir systems would be changed.

5.123 Assumption (h), that there is no transmission gain or loss on the Tigris between Baghdad and Kut, is probably conservative. Analysis of the streamflow data indicates that historical annual gains appear to have occurred frequently, but the analysis depends upon a number of assumptions as to residual inflows from the Diyala tributary, pump abstractions, etc. The possible sources of the gains are also uncertain. Any gains that occur in future conditions of reservoir control are not likely to differ appreciably for alternative reservoir systems and thus do not affect the comparative results.

Dokan Outlet Capacity and Link Canals

5.124 Assumptions (i), (j), and (k) relate to physical conditions under the control of government. Departures from any of them would not affect firm irrigation yields, but distribution of the water would have to be different from that assumed in Tables 5.2 and 5.3.

CHAPTER VI

HYDROELECTRIC POWER PRODUCTION

Summary

Method of Study

Results of Power Studies

Chapter 6

HYDROELECTRIC POWER PRODUCTION

Summary

6.1 Estimates were made of the incidental firm hydroelectric power that could be generated at Samarra Barrage and at Dokan and Derbend-i-Khan dams in alternative reservoir systems which were operated for maximum firm yield of irrigation water. Various minimum flows at these potential power sites were then specified to increase the firm power. The resulting detriments to firm irrigation yields were computed.

6.2 Special attention was devoted to the effects of power production on firm irrigation yield for the existing system of Dokan and Derbend-i-Khan reservoirs. This was done by maintaining specified minimum flows in the irrigation operation studies at the following potential power sites:

- a. Samarra,
- b. Dokan,
- c. Derbend-i-Khan.

The remainder of the studies, with alternative reservoirs added to the existing system, considered effects on irrigation yield of maintaining certain minimum flows at Samarra only.

6.3 In the power studies made by the Hydrological Survey power production was regarded as a by-product of irrigation. The studies

utilized the same electronic computer program as was used for the irrigation operation studies so as to reduce cost to a minimum. Studies with a computer program designed to integrate irrigation usage and power production can be expected to show better power results. The results of this study must, therefore, be viewed as only a preliminary guide to the hydroelectric possibilities at Samarra, Dokan, and Derbend-i-Khan.

Method of Study

Computer Program

6.4 A simple program was developed for supplementing the computer program used for the irrigation operation studies. This supplementary program used the average monthly head and discharge at Samarra Barrage and Dokan and Derbend-i-Khan dams to compute the power potential.

6.5 The irrigation operation program enabled the discharge passing through each plant to be specified at a minimum amount but did not permit a minimum power output to be specified. Such a provision would have required consideration of the variable head that will exist at the dams and integration of power generation and power usage. It would have necessitated the writing, in effect, of a completely new program. In the present stage of uncertainty as to Iraq's development plans it was considered that the cost of writing a new program was not justified and that power results derived from specified minimum flows would be a sufficient guide for the determination of power potential. In the case of Samarra Barrage, the head was practically uniform at all low flows, so specifying the minimum flow also specified the minimum power.

6.6 It likewise followed that, since the computer program did not integrate irrigation and power, operation of the reservoirs and link canals in each system was not coordinated for optimum power. More extensive and detailed studies would reveal power benefits from such coordination, and the results of the studies as carried out show the minimum power outputs that could be generated.

Use of Mean Monthly Flows

6.7 Since the power studies were adaptations of the irrigation studies, they were made on the basis of monthly flows and irrigation requirements. This basis is not entirely suitable for power studies of the Tigris system, but use of data for shorter periods was not considered necessary for this preliminary study. Furthermore, at the time the study was being made, such data, particularly as to irrigation requirements, were not available. The consequent limitations in the results of the power studies are discussed later in this chapter.

Power Plant Characteristics

6.8 Power plant characteristics were taken from the report by J. G. White Engineering Company for Samarra Barrage and from the consultants' project planning reports for Dokan and Derbend-i-Khan dams.

Results of Power Studies

Presentation of Results

6.9 Table 6.1 presents figures obtained from the studies showing the percentage reduction in irrigation yield when minimum flows are specified. Parts (a) and (b) of Exhibit 29 present two typical flow duration curves.

Table 6.1

EFFECT OF MINIMUM POWER FLOWS ON IRRIGATION SUPPLY

System	Minimum Flow In Cusecs		Other Considerations	Annual Irrigation Deliveries		Full Supply (Milliards)	Minimum Flow In Cusecs		Other Considerations	Annual Irrigation Deliveries	
	Sanazra	Dahan Darband-i-Khan		Percent Reduction of Annual Irrigation Deliveries Due to Power	Full Supply (Milliards)		Sanazra	Low Fath Mosul and Low Fatha		Percent Reduction of Annual Irrigation Deliveries Due to Power	
Natural Flow Without Dahan and Darband-i-Khan Reservoirs											
150				17.3							
Initial System, Dahan and Darband-i-Khan Reservoirs											
236				23.1		0	29.2				0
300						0.6					1.1
350						1.6					2.4
400						3.7					4.0
450						4.1					6.3
500						0.4					
227	110			22.2							
228		7%		23.0							
Three-Reservoir System											
Low Fath Mosul											
307				10.4		0					0
350						0.7					0.2
400						1.9					0.5
450						3.4					1.2
500						5.1					2.0
267				28.5							
300						0					0
350						0.2					0.2
400						0.9					1.2
450						3.6					2.3
500						6.0					3.8
Intermediate Fath Mosul											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
High Fath Mosul											
341				11.7		0					0
400						0.2					0.2
450						0.7					0.3
500						1.4					0.7
285				10.1							
350						0					0
400						1.2					0.2
450						2.4					1.2
500						4.3					2.3
Four-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Five-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Six-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Seven-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Eight-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Nine-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Ten-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Eleven-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Twelve-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Thirteen-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Fourteen-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Fifteen-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Sixteen-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Seventeen-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400						1.2					0.3
450						2.4					0.7
500						4.3					
Eighteen-Reservoir System											
320				11.7		0					0
350						0.4					0
400						1.4					0.2
450						2.6					1.2
500						4.0					2.3
285				10.1							
350						0					0
400											

Power at Samarra Barrage

6.10 The minimum flow at Samarra with various reservoirs or systems of reservoirs is shown on Exhibit 30. The minimum power production at Samarra can be maintained at 23.5 megawatts with the maximum irrigation yield that the existing system can support. With a reduction of only 1.6 percent in firm irrigation yield in the basic study period, the minimum power production can be maintained at 34.8 megawatts. Thus, substantial power benefits could accrue with very slight reductions in dependable irrigation deliveries.

6.11 Exhibit 30 shows that as the reservoir system increases in size the minimum flow and, therefore, power at Samarra also increase. However, the increase in firm power that could be produced at Samarra will not be uniform throughout the development period. Each time additional onstream storage is added to the system there will be a large increase in minimum flow available for power purposes, because irrigation demands will not immediately increase to the point of requiring the full regulating capacity of the reservoirs, and this capacity can be used on a temporary basis for power purposes. Until the next increment of storage is added, a gradual decrease in minimum flows at Samarra will follow as the available storage capacity is used more exclusively for irrigation.

6.12 There are three ways in which the minimum flow at Samarra might be increased over the figures shown on Exhibit 30. These are:

- a. Increased irrigation requirements below Samarra:
The studies were run using the preliminary estimates of irrigation requirements as furnished by other consultants. If values containing greatly increased requirements below Kut had been used, minimum flows at Samarra would have been substantially higher.

- b. Reservoir operation to provide the minimum flows required for navigation below Kut: In this case a larger amount of power could be produced at Samarra. The effect of ensuring minimum flows for navigation is discussed in greater detail in Chapter 7.
- c. Irrigation diversion for use in the Nahrwan area being made downstream instead of upstream of Samarra: In this way minimum flows through Samarra Barrage would be substantially increased.

6.13 It was remarked in Chapter 5, paragraph 5.30, that flows at Samarra were assumed in the studies to be identical with those at Fatha. In case of any historical loss between Fatha and Baghdad, it was assumed to be concentrated in the reach below Samarra, and the Samarra flow was correspondingly increased. If further discharge measurements reveal that a significant proportion of the loss occurs above Samarra, the total flow and power capabilities at Samarra would be reduced. However, the firm power capabilities shown on Table 6.1 would be very little affected since they are governed by conditions existing in the month of October, when historical losses between Fatha and Baghdad were small.

6.14 The use of mean monthly flows instead of daily or weekly data did not affect the results at Samarra, because the month of October has relatively uniform flow.

6.15 Use of Wadi Tharthar for irrigation storage would reduce the annual flows available for power generation at Samarra since flows surplus to downstream irrigation requirements would be diverted into Wadi Tharthar for storage. In addition, in any system including irrigation storage in Wadi Tharthar, that reservoir should be drawn down first to decrease the evaporation losses. Increase of firm power at Samarra would interfere with this type of operation and, therefore, increase the

system evaporation losses. Thus, the use of Wadi Tharthar for irrigation storage is not compatible with power production at Samarra.

Power at Dokan and Derbend-i-Khan Dams

6.16 Table 6.1 also shows that for the existing system substantial amounts of power can be produced at both Dokan and Derbend-i-Khan with only minor effects on irrigation yields. An incidental advantage of power production at Dokan would be the increase in outlet capacity furnished by the power penstocks, a capacity which will be required for irrigation requirements to be met in full.

6.17 At the damsites, firm power without waste of irrigation water is governed by the winter months of December and January. During these months not only is there usually a wide day-to-day variation in the uncontrolled flows which supply part of the irrigation demand, but also the demand varies according to incidence of rainfall. Therefore, it would not be possible to maintain a uniform mean monthly release in those months without releasing (and thus wasting) water not required for irrigation purposes. The results shown on the table can, therefore, be treated only as an indication of the firm power possibilities, pending more refined studies.

6.18 The projected Lesser Zab-Diyala Link Canal would give an opportunity to combine operations of Dokan and Derbend-i-Khan reservoirs in such a way as to increase firm power without detriment to irrigation. For this purpose it might be necessary to increase capacity of the link canal beyond that required for irrigation supplies alone. An investigation of these possibilities would be a major task and was beyond the scope of the Hydrological Survey assignment.

CHAPTER VII

INTEGRATED USES OF ALTERNATIVE
RESERVOIR SYSTEMS

Introduction

Criteria for Ultimate Development

Irrigation and Flood Control

Other Uses of Water Resources

Comparison of Reservoir Systems

Recommended Systems of Reservoirs

Intermediate Use of Surplus Storage

Chapter 7

INTEGRATED USES OF ALTERNATIVE RESERVOIR SYSTEMS

Introduction

7.1 The results of the operation studies conducted separately for flood control, irrigation, and power have been presented in Chapters 4, 5, and 6. In this chapter we consider how these uses can be integrated and the way in which other uses which we have rated to be of lesser importance may be satisfied. Assessments are made of the relative merits of various reservoir systems for controlling the Tigris River system for all purposes. The interim use of storage while irrigation development is under way also is discussed.

Criteria For Ultimate Development

Principal Water Uses

7.2 The principal uses to which a system of Tigris reservoirs can be put are:

- a. Flood protection
- b. Irrigation
- c. Production of hydroelectric power
- d. Navigation
- e. Rice cultivation by flooding methods.

The ultimate development plan will be a compromise among these conflicting interests and demands. It will be affected by economic, social,

and political considerations relating to Iraq as a whole, of which the hydrological aspects discussed in this chapter will form a part, though probably the most important part.

7.3 The ultimate development must be one which makes optimum use of Iraq's water resources for the purposes mentioned in the above paragraph. A most important criterion is that the ultimate plan of development should be well conceived, in advance of construction of interim stages, so that these stages can be accomplished without precluding the best ultimate plan. At the same time, an evaluation of the benefits from interim stages is important because the possibility always exists that the ultimate development may never be attained.

7.4 We have assumed in our Tigris operation studies that the most important purposes of development are (a) to increase irrigation to the maximum and (b) to provide a high degree of flood protection. Studies were undertaken to find the effect on irrigation yield of assuming minimum flows at some of the potential hydroelectric power sites, but we have considered production of power primarily as a by-product of irrigation. We have considered navigation to be of minor importance unless it can be combined with irrigation requirements, and we have taken rice flooding to be a temporary expedient.

Interests of Lower Iraq

7.5 The interests of lower Iraq may be seriously affected by the degree and method of utilization of Tigris water resources. Factors of importance in this connection are the following:

- a. Salinity of river flows in the lower reaches can become a problem if irrigation development is such that drainage outfalls from the upstream areas discharge into the Tigris. It may then be necessary to maintain minimum river flows to hold the salinity at a safe level, depending upon the type of irrigation development in lower Iraq.
- b. Developments on the Karun and Kharkeh rivers in Iran may allow serious intrusion of sea water into the Shatt-el-Arab, with a consequent deterioration of its riparian date gardens, unless fairly substantial contributions are made from the Tigris and Euphrates.
- c. The present economic and social well-being of the inhabitants of Hammar Lake and its neighboring marsh areas is largely dependent upon Tigris spills. The latter could be reduced to smaller proportions than at present without creating much hardship, but there is a limit below which the spills could not be lowered without the inhabitants' having to seek a new livelihood elsewhere.

7.6 On account of these factors we have considered the relative amounts of spill from alternative reservoir systems to be of some importance but not a major criterion. Future developments and government policy arising from them may lead to other views.

Effect of Future Developments in Iran and Turkey

7.7 The effect of future developments in Iran and Turkey was not taken into account in the irrigation and flood-control operation studies for the Tigris River Basin. The plans for any such developments are vague; therefore, in our comparative evaluations of reservoir developments in Iraq the developments in upstream countries could be considered only qualitatively.

7.8 The significant part of the Tigris Basin that lies in Iran is mostly in the headwaters of the major tributaries. The effect of any future developments on the larger tributaries would be small, unless diversion were made from the Tigris Basin to areas outside the basin. We are not aware of any plans for such diversions in Iran.

7.9 We believe that developments on the Tigris River in Turkey will not be made until substantial developments have occurred there on the Euphrates River and also that the effect of such developments on the Tigris flow will be smaller than the corresponding effect on the Euphrates. The Euphrates Basin in Turkey has greater irrigation potential, and its location closer to major population centers also favors it for initial power development.

7.10 A large storage reservoir on the Tigris River in Turkey would reduce the flood potential at all points on the Tigris River in Iraq. The most likely site for a large reservoir is too far downstream to provide water for irrigation of any sizeable area in Turkey, so its use necessarily would be primarily for power. Such operation would be beneficial to Iraq since it would tend to stabilize the flow of the river and reduce the needs for storage in Iraq. Its construction would provide part of the regulation we have estimated as being furnished by Eski Mosul Reservoir and would thus significantly reduce the incremental benefits that we have indicated as resulting from construction of Eski Mosul Dam.

Cost Considerations

7.11 The final and usually the most important consideration in selecting a plan for river development and control is the economic benefit that can be obtained, taking into account all the purposes which alternative

plans will achieve. This type of evaluation was not included in our assignment, which was confined to making an assessment on hydrological grounds. However, capital costs of reservoirs, where estimated by other consultants, have been used in arriving at our conclusions.

Effect of Basic Assumptions

7.12 We have based our conclusions as to the comparative merits of each system of reservoirs upon the best use we could make of the hydrological and other data available. It was necessary also to make a number of assumptions. These have been discussed in detail in Chapters 3, 4, 5, and 6, and will not be repeated in this chapter. However, the reader is reminded that our conclusions depend to some extent upon the validity of those assumptions.

Irrigation and Flood Control

Methods of Meeting Conflicting Requirements

7.13 It is essential for effective flood control that, during the season in which floods can occur, sufficient empty space be maintained in reservoirs to store all possible flow in excess of that which can be safely carried by the river channels. It is essential for maximum irrigation benefits that irrigation reservoirs be as nearly full as possible at the start of the season of reservoir drawdown.

7.14 There are three principal methods of achieving the two objectives. One method is to have separate reservoirs for each purpose. Flood-control reservoirs are kept empty at all times except during floods, while irrigation reservoirs are kept as nearly full as the water requirements for irrigation will permit. This method is being followed in some

countries where hydrologic conditions are such that joint use of reservoir space for the two purposes is not feasible, where different authorities are responsible for the two objectives and there is inadequate coordination between the organizations, or where legal requirements dictate such operation.

7.15 The second method is to reserve space in the top part of a reservoir exclusively for flood-control purposes while using the lower part of the reservoir exclusively for irrigation storage. In this type of operation the water level in the reservoir is never allowed to exceed a specified elevation except for temporary storage of flood flows. On the other hand, the water level is never allowed to fall below that elevation except when releases are required for irrigation. This type of operation is fairly common in areas where floods can be expected at any time of the year.

7.16 Iraq is fortunate in that floods occur only during a definite season. This makes possible the third or "joint use" method of operation. This method differs from the second in that the specified elevation which divides the flood-control part of the reservoir from the irrigation part changes with the seasons, in accord with the "rule curve," and sometimes also with the forecast of future runoff. This method of operation, where practicable, is the most economical and has been followed in all our flood-control and irrigation studies. It represents true integration of uses.

7.17 The rule curves presented on Exhibit 21 and Table 5.6 represent guides for operation, for both interim and ultimate conditions, which will be very useful for actual operational purposes. The use of seasonal streamflow forecasts can increase further the opportunity for joint use of reservoir storage; this will be discussed in Chapter 8. Further considerations which might affect the application of the rule curves will include

interim use of storage for purposes other than irrigation and maintenance of minimum flows for power production, discussed later in this chapter and in Chapter 8.

Flood Control and Irrigation Usage

7.18 The operation studies for flood control (Table 4.2) show that several systems of reservoirs upstream from Samarra can give nearly complete flood protection to Baghdad and downstream areas. However, the possibility does exist for extreme flood-producing storms to be centered over the Adhaim and lower Diyala rivers, and the protection of Baghdad cannot be complete without flood-control facilities on these rivers.

7.19 The results of the irrigation operation studies (Table 5.1) show that 23 reservoir systems (excluding systems with two milliards dead storage in Fatha Reservoir) will develop over 32 milliards per year of firm irrigation yield, which is about 85 percent of the firm irrigation yield developed by the system which was found to have the highest yield of all those studied. The 23 systems are listed in Table 7.1. Nineteen of these reservoir systems would also give practically full protection to Baghdad and the lower Tigris from floods caused by storms centered above Samarra. Other aspects affecting their relative merits are discussed later in this chapter.

Other Uses of Water Resources

Power Production

7.20 It has been demonstrated in Chapter 6 that considerable quantities of power can be produced at Dokan, Derbend-i-Khan, and Samarra

Table 7.1

RESERVOIR SYSTEMS PROVIDING HIGHEST LEVELS OF IRRIGATION YIELD

<u>Reservoirs in Addition to Existing System of Dokan and Derbend-i-Khan Reservoirs</u>	<u>Total Number of Reservoirs in System</u>	<u>Firm Irrigation Yield (Milliards of M³)</u>	<u>Percentage of Maximum Firm Irrigation Yield</u>	<u>Complete Flood Protection to Baghdad^{1/}</u>
High Eski Mosul (335), High Bekhme (550), and Low-Outlet Wadi Tharthar (35)	5	38.0	100.0	yes
High Eski Mosul (335), High Bekhme (550), and High Fatha (178)	5	37.7	99.2	yes
Low Eski Mosul (320), High Bekhme (550), and Low-Outlet Wadi Tharthar (35)	5	37.0	97.4	yes
Low Eski Mosul (320), High Bekhme (550), and High Fatha (178)	5	36.7	96.6	yes
High Bekhme (550) and High Fatha (178)	4	36.1	95.0	yes
High Bekhme (550) and Intermediate Fatha (172.5)	4	35.9	94.5	yes
Low Eski Mosul (320) and High Fatha (178)	4	35.3	92.9	yes
High Eski Mosul (335) and High Bekhme (550)	4	35.2	92.6	yes
Low Eski Mosul (320) and Intermediate Fatha (172.5) (without Jazira)	4	35.1	92.4	yes
High Fatha (178)	3	35.1	92.4	yes
High Bekhme (550) and Low-Level Wadi Tharthar (35)	4	35.1	92.4	no
Low Eski Mosul (320) and Low-Level Wadi Tharthar (35)	4	34.4	90.5	no
Intermediate Fatha (172.5)	3	34.3	90.3	yes
Intermediate Eski Mosul and High Bekhme (550) (without Jazira)	4	34.5	90.8	yes
Low Eski Mosul (320) and High Bekhme (550) (without Jazira)	4	34.1	89.7	yes
Low Eski Mosul (320), Low Bekhme (500), and Low Fatha (165)	5	34.0	89.5	yes
Low-Outlet Wadi Tharthar (35)	3	33.8	88.9	no
High Eski Mosul (335) (without Jazira)	3	33.7	88.7	practically
Low Eski Mosul (320) and High Bekhme (550)	4	33.5	88.2	yes
Low Eski Mosul (320) and Low Fatha (165)	4	33.1	87.1	yes
Intermediate-Outlet Wadi Tharthar (40)	3	32.8	86.3	no
High Eski Mosul (335)	3	32.2	84.7	practically
Low Bekhme (500) and Low Fatha (165)	4	32.0	84.2	yes

All systems with Eski Mosul include high dead storage for service to the Jazira Project unless otherwise noted.

All systems with Fatha include 4 milliards dead storage.

1/ Except for Spates on the Adhaim and Lower Diyala rivers

without any releases being made specifically for power production purposes. By making small special releases to maintain certain minimum flows, the minimum continuous power can be greatly increased with only very small reductions in the irrigation yields.

Navigation

7.21 Preliminary information furnished by Tippetts-Abbott-McCarthy-Stratton, Consulting Engineers, indicated that the flow required for navigation below Kut would be 325 cumecs in 1975 and 225 cumecs in 1985. The decrease for 1985 was predicted on certain channel improvements¹ being made. The navigation studies we have made were based on these assumptions. There is some coincident use of water for irrigation and navigation, and therefore integration of these uses has been considered to the maximum extent possible.

7.22 Later thinking of the consultant was that ultimately navigation depths below Kut would be maintained by river control structures rather than by adhering to specified flows. If this objective is realized, full integration of irrigation and navigation would be obtained in the ultimate stage with no increase in deliveries especially to serve navigation.

7.23 The effects of navigation on system operation can be obtained from Table 7.2, which shows that the ultimate irrigation yield of the existing two-reservoir system would be reduced from 23.1 milliards to 15.7 milliards of cubic meters per year if navigation requirements below Kut are to be met. As the irrigated areas and reservoir systems grow, the conflict between irrigation and navigation will decrease, partly because the increased flows required for irrigation will meet more of the navigation requirements and partly because channel improvements are

Table 7.2

EFFECT ON IRRIGATION YIELD OF MEETING NAVIGATION
REQUIREMENTS BELOW KUT

Study No.	Reservoir System (Additions to the Existing System of Dokan and Derbend-i-Khan Reservoirs)	Minimum Monthly Flow		Annual Irrigation Yield	
		Below Kut (cumecs)	Below Samarra (cumecs)	(milliards)	% Reduction Due to Navigation
20(b) 17(c)	No Additions	69 325 <u>1/</u>	236 438	23.1 15.7	32
115 70	Low Eski Mosul	75 325 <u>1/</u>	307 432	30.4 22.3	27
114(b) 22(b)	High Bekhme	77 315 <u>1/</u>	313 431	31.0 24.3	22
83 32	High Fatha	87 265 <u>1/</u>	355 426	35.1 31.2	11
82(b) 55	Wadi Tharthar (Low-Level Outlet)	84 235 <u>1/</u>	150 <u>2/</u> 150 <u>2/</u>	33.8 31.3	7.4
80 30	High Eski Mosul, High Bekhme	81 265 <u>1/</u>	331 419	35.2 32.3	8.2
72(b) 73	Low Eski Mosul, Wadi Tharthar (Low-Level Outlet)	79 265 <u>1/</u>	150 <u>2/</u> 150 <u>2/</u>	34.4 30.2	12
74 66	Low Eski Mosul, High Bekhme, Wadi Tharthar (Low-Level Outlet)	85 230	150 <u>2/</u> 150 <u>2/</u>	37.0 35.0	5.4

1/ Navigation requirement.

2/ Assumed requirement for amenities.

expected to reduce the flow required for navigation. As an example, studies for the high Fatha Dam added to the existing system show that the irrigation deliveries would be reduced only from 35.1 to about 31.2 milliards per year if navigation requirements of 265 cumecs were served.

Rice Flooding

7.24 Annual rice flooding requirements have been derived from preliminary data furnished by Tippetts-Abbott-McCarthy-Stratton. They are in terms of an average flow during March and April below Kut. The approximate estimated requirements are 3000 cumecs (16 milliards per year) at present, 1500 cumecs (8 milliards per year) in 1975, and none in 1985. It has been further reported informally that the required volumes could be distributed over the February-through-May period if necessary. No attempt was made to meet these requirements in the operation studies. However, the water available for rice flooding, incidental to other operations, was computed for several typical studies. The results (which are in fact "system spills") are shown in Table 7.3, which gives February-through-May flow in excess of normal irrigation requirements with certain reservoir systems.

7.25 The decrease from present to 1975 rice flooding requirements is made on the assumption that the Musandaq Escape will be controlled sometime before 1975. The actual rice flooding requirements are expected to remain nearly constant until the Musandaq Escape is controlled, but after that time the river flow need not be as great to raise the river level sufficiently to enable the flood waters to be diverted.

7.26 The decrease in requirements from 1500 cumecs in 1975 to none in 1985 is based on the assumption that chemical fertilizers will

Table 7.3

FLOWS AVAILABLE FOR RICE FLOODING
WHILE DEVELOPING MAXIMUM FIRM IRRIGATION YIELD

Year	Dokan and Derbend-i-Khan Reservoirs Annual Firm Irrigation Yield 23.1 Milliards		Dokan, Derbend-i-Khan, and Low Eski Mosul Reservoir Annual Firm Irrigation Yield 28.5 Milliards		Dokan, Derbend-i-Khan, and Low-Level-Outlet Wadi Tharthar Annual Firm Irrigation Yield 33.8 Milliards	
	Excess Feb. -May Flow Milliards	% of 1975 Rice Flooding Requirements of 8 Milliards	Excess Feb. -May Flow Milliards	% of 1975 Rice Flooding Requirements of 8 Milliards	Excess Feb. -May Flow Milliards	% of 1975 Rice Flooding Requirements of 8 Milliards
1930	2.5	31	0.8	10	1.5	19
1931	11.0	138	4.6	58	0.7	9
1932	9.3	116	3.0	38	0.8	10
1933	11.2	140	3.6	45	1.4	18
1934	9.1	114	2.1	26	1.2	15
1935	12.5	156	6.5	81	0.7	9
1936	15.4	193	8.4	105	1.5	19
1937	14.5	181	8.9	111	0.9	11
1938	25.8	322	18.9	236	1.6	20
1939	26.9	336	20.2	252	9.7	121
1940	29.7	371	22.6	282	14.6	182
1941	30.4	380	24.0	300	17.5	219
1942	23.2	290	17.0	212	9.2	115
1943	22.8	285	15.6	195	9.2	115
1944	18.6	232	13.2	165	5.6	70
1945	10.4	130	4.8	60	4.0	50
1946	31.5	394	23.4	292	4.5	56
1947	10.2	127	5.3	66	6.5	81
1948	16.5	206	10.7	134	0.4	5
1949	22.2	278	12.9	161	2.2	28
1950	23.3	291	16.6	208	11.7	146
1951	6.2	76	0.8	10	1.8	22
1952	18.1	226	13.1	164	0.8	10
1953	24.4	305	16.9	211	3.8	48
1954	41.6	520	34.0	425	22.9	286
1955	5.5	69	0.7	9	2.6	32
1956	16.4	205	10.4	130	0.8	10
Average	18.1		11.8		5.1	

replace the current practice of fertilization by silt deposition. Such a decrease is not at all certain. Therefore, the water available for rice flooding during that period is shown in all three systems in Table 7.3 in terms of percentage of the requirements that are estimated to be in effect in 1975.

7.27 The results in Table 7.3 indicate that, with operations giving strict priority to normal irrigation, the 1975 rice flooding requirements would be fully met by the existing reservoir system (firm irrigation yield 23.1 milliards per year) in all but three of the 27 years of the study. With the addition of a low Eski Mosul to the system and the firm irrigation yield raised to 28.5 milliards per year, the 1975 rice flooding requirements would not be met in ten of the 27 years. With the addition of Wadi Tharthar to the system and the firm irrigation yield still further raised to 33.8 milliards per year, the water available for rice flooding would be less than the 1975 requirements in 20 of the 27 years. There could be some additional benefits to rice flooding if the strict priority given to irrigation were relaxed. However, the increased benefits would be small in relation to the water lost to normal irrigation usage.

Municipal Use and Amenities

7.28 The irrigation operation studies specified minimum flows of ten cumecs on the Greater Zab and Lesser Zab rivers, 30 cumecs on the upper Tigris, and 150 cumecs on the Tigris below Samarra. These flows were considered sufficient to satisfy such amenities as municipal water supply at Kirkuk, Mosul, and Baghdad, as well as power plant cooling, sanitation, and maintenance of fish life. The specified minimum flows occur only infrequently during normal operation of the reservoir systems.

An indication of the frequency of low flows at Baghdad may be obtained from the flow duration curves for Samarra shown on Exhibit 30.

Comparison of Reservoir Systems

Criteria for Comparison

7.29 In assessing the relative values of various proposed additions to the Tigris River reservoir system, the following considerations have influenced our judgment:

- a. Flood protection provided at Samarra and downstream
- b. Yield of irrigation water
- c. Hydroelectric power production
- d. Costs (to the extent data are available)
- e. Ease and convenience of operating each system
- f. Interim value of initial stages of the ultimate development
- g. Possibility of developing 800, 000 mesharas of land for irrigation in the Jazira Project near Mosul (This is considered by the reporting consultant to be feasible only if Eski Mosul Dam is built.)
- h. Flood protection provided to the city of Mosul
- i. Amounts of water lost by evaporation, which is related to system spills and amounts by which reservoirs failed to fill during the basic study period.

7.30 The use of water for navigation and rice flooding has also been considered, but these functions are modifications of the irrigation delivery pattern, so that consideration given to irrigation yield applies to them also.

7.31 Our conclusions regarding the relative merits of various reservoir systems are based on the data presented in Tables 4.2, 5.1, 6.1, 7.1, 7.2, 7.3, and 7.4. Merits of individual reservoirs and projects are discussed in the following paragraphs.

Five-Reservoir Systems

7.32 It is apparent that systems including any three reservoirs in addition to Dokan and Derbend-i-Khan reservoirs compare unfavorably in cost with systems including any two additional reservoirs. The addition of three reservoirs gives little benefit, from the point of view of both flood control and irrigation storage, beyond what is achieved by the addition of only two reservoirs, and furthermore leads to greater permanent loss of water by evaporation. Accordingly, the five-reservoir systems do not appear to merit serious consideration.

Wadi Tharthar Reservoir

7.33 Wadi Tharthar alone, without any other reservoir, is ideal for handling high seasonal flood volumes but is limited in its capacity to handle peaks. Our computations show that a potential exists for a flood that would require a diversion capacity of about 29,000 cumecs, three times that of the present escape regulator at Samarra Barrage and possibly four times that of the present diversion channel. The cost of enlarging the present facilities must therefore be added to the cost of developing Wadi

Tharthar as the only additional reservoir for irrigation, the extent of the enlargement being dependent on a policy decision as to the flood probability to be protected against.

7.34 Loss of potential irrigation water due to evaporation would be substantially higher from Wadi Tharthar than from any other reservoir. This greatly reduces system spills, relative to its firm irrigation yield, to the detriment of lower Iraq.

7.35 The higher evaporation loss from Wadi Tharthar results also in a substantially larger decrease in reservoir content between beginning and end of the basic study period, as compared with systems not including Wadi Tharthar. This was not important during the historical period of river flows because the basic study period was followed by a period of higher than average flows. However, future sequences of river flows could well be less favorable. Use of Wadi Tharthar for irrigation storage would thus be a constant source of anxiety during low river cycles since many years might pass before it could be filled again to cope with the next low cycle.

7.36 Other disadvantages of Wadi Tharthar for irrigation storage have been referred to in Chapter 5. Among these disadvantages are:

- a. The extreme care required in operation to avoid its water's becoming too saline for safe irrigation usage.
- b. The possible long period required for initial filling of the reservoir to outlet level
- c. The reduced benefits of Samarra Barrage as a potential hydroelectric power site
- d. The fact that Wadi Tharthar itself has no power potentialities.

7.37 We conclude that the only advantages of Wadi Tharthar for irrigation storage, as compared with other projected reservoirs, are relative simplicity of construction and possibly lower costs.

Eski Mosul and Bekhme Reservoirs

7.38 The degree of flood protection afforded to Samarra and downstream locations by any Eski Mosul alternative is considerably higher than that afforded by a high Bekhme Dam. Low Eski Mosul is capable of protecting Baghdad against 75 percent of the probable maximum flood (with the present diversion capacity at Wadi Tharthar), while Bekhme would only protect against 50 percent. Eski Mosul also has greater benefits for overall flood protection during the interim stages of irrigation development.

7.39 Any Eski Mosul Dam would provide flood protection for the city of Mosul. By holding a high dead storage level it would facilitate development of irrigation projects in the neighbourhood of Mosul and would provide opportunity for irrigation development of 800,000 mesharas in the Jazira Project near Mosul. Bekhme Reservoir would provide only small local benefits. The addition of any height of Eski Mosul alone, as an initial stage toward ultimate development, would give much greater benefit for flood control than Bekhme during interim stages of irrigation development, while the high Eski Mosul gives a greater irrigation yield than a high Bekhme. The cost of a high Bekhme Dam is only about 15 percent less than that of a low Eski Mosul Dam and about 25 percent less than that of a high Eski Mosul, excluding the cost of lands occupied by the reservoirs. Therefore, Eski Mosul is to be preferred over Bekhme in those systems of reservoirs which include either of them as alternatives.

7.40 While these factors favor Eski Mosul over Bekhme, two possible considerations could project Bekhme into a more favorable position. The first would be the construction of a dam on the main stem of the Tigris River in Turkey; this would reduce the incremental benefits from a reservoir at Eski Mosul. The second would be a large demand for hydroelectric power, in which case Bekhme could have substantial advantages. For these reasons we have retained the Bekhme Dam as an alternative, combined with a dam at either Eski Mosul or Fatha.

7.41 The consultant's report on Eski Mosul indicates that a low dam could be constructed initially and later raised to the higher elevation with only about a one-percent increase in total cost over the cost of constructing the dam to its ultimate height initially. Thus, the Government of Iraq might elect to construct Eski Mosul in stages, since very substantial benefits can accrue from the low Eski Mosul alone. The question would then arise as to whether the next stage of development should be the raising of Eski Mosul or the construction of Bekhme.

7.42 Table 4.2 indicates that the flood reductions at Samarra resulting from the raising of Eski Mosul to its full height are very similar to those obtained by adding Bekhme to a low Eski Mosul. The firm irrigation yield of these alternatives can best be compared if the Jazira unit is not included. In this case the yield from the low Eski Mosul - high Bekhme combination would be 89.7 percent of the maximum system potential, compared with 88.7 percent for high Eski Mosul alone. Since the cost of construction of Bekhme would be over five times the cost of raising of Eski Mosul, it follows that the raising of Eski Mosul would be the more desirable step, unless power production becomes important or a dam is constructed on the Tigris in Turkey.

Fatha Reservoir

7.43 We understand that the physical feasibility and estimated cost of a dam on the Tigris at or near Fatha are now being investigated by a team of Soviet engineers engaged by the Government of Iraq. For the purpose of this report we have assumed that a feasible damsite is available and that construction costs would be such that a Fatha Reservoir can be compared on hydrological and other grounds with alternative reservoir systems.

7.44 With regard to flood control, we showed in Chapter 4 (paragraphs 4.27 and 4.28) that for areas downstream of Samarra, Fatha Reservoir alone provides more effective control than Eski Mosul and Bekhme together. Because of Fatha's strategic position, it would also afford a more easily operated means of control.

7.45 The firm irrigation yield developed by addition of a high-level Fatha Reservoir alone is practically as high as that developed by a combination of reservoirs excluding Fatha, except the five-reservoir systems. A high-level Fatha develops approximately the same yield as Eski Mosul and Bekhme together, both at high levels. The reason for the good yields from Fatha is that torrential inflows below the upstream reservoirs could be controlled by Fatha, whereas when Fatha Reservoir is not in the system these inflows cause flow fluctuations between Fatha and Baghdad, with consequent losses and some of the inflows going to system spill.

7.46 On the other hand, evaporation losses from Fatha alone are higher than from Eski Mosul and Bekhme together and thus result in smaller system spills and a greater reduction of reservoir content between the beginning and end of the basic study period.

7.47 The local benefits provided by an Eski Mosul Reservoir, especially if it were held at a high dead-storage level with some sacrifice of irrigation yield, also favor Eski Mosul over Fatha as well as Bekhme. Fatha Reservoir would have only marginal local benefits, which probably would be more than outweighed by the presently cultivated land that would be inundated and by the necessity to relocate some main roads and railway tracks.

7.48 In comparing the firm irrigation yields developed by Fatha and Eski Mosul reservoirs, the quality of the irrigation projects that can be served from each reservoir must be considered. Fatha can serve only projects south of the Jebel Hamrin and relieve the load upon Dokan and Derbend-i-Khan reservoirs, provided the link canal mentioned in paragraph 5.67 of Chapter 5 is constructed. Eski Mosul can serve projects in northern Iraq as well. Should the northern projects be of better quality than the southern, then the extra water developed by Fatha might not produce a commensurate benefit.

Recommended Systems of Reservoirs

7.49 On the basis of the various factors discussed in the preceding paragraphs, we have selected six systems which we consider the most promising. These six systems, together with their potential initial and ultimate benefits, are listed in Table 7.4.

7.50 The most promising reservoir sites are limited to Eski Mosul, Fatha, and Bekhme. As an initial stage Bekhme offers less benefits for both flood control and irrigation, at probably higher cost, than either Fatha or Eski Mosul. Thus, the choice for initial development can be narrowed to Fatha and Eski Mosul. The selected criteria for ultimate

Table 7.4
SUMMARY OF OPERATION STUDIES OF MOST PROMISING RESERVOIR SYSTEMS

System Additions to Bikan, Derband-i-Khan, and Existing Wall Tharshar	Total Dead Storage of System (milliards)	System Active Storage (milliards)	Flood Peak			Flood Peak at Mosul			Is flood protection provided to Mosul?	Annual System Firm Irrigation Yield			Can Irrigation Project be developed?	Minimum Flow at Samarra for Power (cusecs)	Approximate Construction Cost of Additions to System 2/ (millions of ID)	Remarks	
			Above Samarra Damages			Probable Maximum (cusecs)				Probable Maximum (cusecs)	Total (milliards)	% of Basin (Percent)					Additional to Existing System (milliards)
			Probable Maximum (cusecs)	Probable Maximum (cusecs)	Probable Maximum (cusecs)												
Natural flow with no reservoir	-	0	37,500	27,800	18,500	30,000	22,500	15,000	No	17.3	45.5	-	No	150	-		
No additional reservoir	-	8.8	35,700	23,600	15,800	30,000	22,500	15,000	No	23.1	40.8	-	No	236	-		
BENEFITS FROM ULTIMATE SYSTEMS																	
1 High Eski Mosul	3.0 0.5	19.0 21.5	18,100 18,100	14,200 14,200	11,300 11,300	10,600 10,600	6,000 6,000	5,000 5,000	Yes Yes	32.2 33.7	84.7 86.7	9.1 10.6	Yes No	302 341	52.1 2/	Reasonable control of floods throughout system and good irrigation yield. With high dead storage allows Jaskira Development.	
2 Intermediate Fatha	4.0 2.0	22.8 24.8	15,000 15,000	10,000 10,000	9,900 9,900	30,000 30,000	22,500 22,500	15,000 15,000	No No	34.3 34.7	90.3 91.3	11.2 11.6	No No	347 351	Possibly higher than System 1	Good control of Baghdad floods and good irrigation yield. No control of Mosul floods and no Jaskira Development.	
3 High Fatha	4.0	28.9	15,000	10,000	9,800	30,000	22,500	15,000	No	35.1	92.4	12.0	No	355	Probably higher than System 1	Excellent control of Baghdad floods and high irrigation yield. No control of Mosul floods and no Jaskira Development.	
4 Low Eski Mosul and Low Fatha	7.0 5.0	21.3 23.1	10,000 10,000	10,000 10,000	9,600 9,600	13,000 13,000	10,500 10,500	5,000 5,000	Yes Yes	32.9 33.9	86.5 89.2	9.8 10.8	Yes Yes	311 318	Undoubtedly higher than System 1	Excellent control of floods throughout system and good irrigation yield. Eski Mosul high dead storage allows Jaskira Development. Probably high cost.	
5 High Eski Mosul and High Babine	3.5	26.8	15,800	12,400	9,700	10,600	6,000	5,000	Yes	35.2	92.6	12.1	Yes	331	90.9	Adds comparatively small increment to benefits obtained from Fathi Mosul alone. Babine worthy of consideration only if power becomes important or if dams are built in Turkey.	
6 Intermediate Fatha and High Babine	4.5	30.6	10,000	10,000	9,600	30,000	22,500	15,000	No	35.6	91.7	12.5	No	363	Undoubtedly high	Adds comparatively small benefits to intermediate Fatha alone. Addition of Babine worthy of consideration only if power becomes important.	
INTERIM BENEFITS FROM ALTERNATIVE STAGES OF ABOVE ULTIMATE SYSTEMS																	
A Low Eski Mosul, as initial stage of Systems 1, 4, or 5	3.0 0.5	13.5 16.0	19,200 17,200	14,400 14,400	10,900 10,900	12,900 12,900	10,300 10,300	5,000 5,000	Yes Yes	28.5 30.4	75.0 80.0	5.4 7.1	Yes No	267 308	45.6 2/	Lowest cost, substantial benefits throughout system, flexible in fitting alternative future plans.	
B High Babine, as initial stage of System 5	0.5	16.6	27,000	16,600	12,900	30,000	22,500	15,000	No	31.0	81.6	7.9	No	313	38.6 4/	Much less general benefit than Alternative A, without significantly lower cost.	
C Low Fatha, as initial stage of Systems 2, 3, 4, or 6	4.0 2.0	16.6 18.6	18,000 18,000	10,000 10,000	9,900 9,900	30,000 30,000	22,500 22,500	15,000 15,000	No No	30.3 31.5	79.7 82.4	7.2 8.2	No No	307 316	Not known	Less general benefit than Alternative A, at probably higher cost.	

1/ Where two values are shown, those represent alternatives of dead storage.
 2/ Not including cost of power facilities or purchase of lands and damages.
 3/ 1910 cost estimate.
 4/ 1951 cost estimate of Babine at 10 M, 28% on, adjusted to 1940 by 1.5.
 Source of Reservoir cost index.

Reservoir Description

Reservoir	Normal Maximum Reservoir Elevation
Low Eski Mosul	320
High Eski Mosul	335
High Babine	350
Low Fatha	165
Intermediate Fatha	172.5
High Fatha	178

Lowest cost, substantial benefits throughout system, feasible in fitting alternative future phase.

Much less general benefit than Alternative A, without significantly lower cost.

Less general benefit than Alternative A, at probably higher cost.

Reasonable control of floods throughout system and good irrigation yield. With high dead storage allows Jazira Development.

Good control of Baghdad floods and good irrigation yield. No control of Mosul floods and no Jazira Development.

Excellent control of Baghdad floods and high irrigation yield. No control of Mosul floods and no Jazira Development.

Excellent control of floods throughout system and good irrigation yield. Peki Mosul high dead storage allows Jazira Development. Probably high cost.

Adds comparatively small increment to benefits obtained from Eski Mosul alone. Babine worthy of consideration only if power becomes important or if dams are built in Turkey.

Adds comparatively small benefits to Intermediate Fatha alone. Addition of Babine worthy of consideration only if power becomes important.

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SUMMARY OF OPERATION STUDIES OF MOST PROMISING RESERVOIR SYSTEMS

System Design to Dokan, Deband-1 or Dokan, Deband-1 or Dokan, Deband-1	System Additions Khan, Thattara or Dokan, Deband-1 or Dokan, Deband-1 or Dokan, Deband-1	Natural flow with no reservoirs	No additional reservoirs	BENEFITS FROM ULTIMATE SYSTEMS										Remarks	
				Total (milliards)	Dead Storage of System 1/ (milliards)	System Active (milliards)	Flood Peak above Sumatra Maximum (cumees)	Flood Peak 50% Probable Maximum (cumees)	Flood Peak 75% Probable Maximum (cumees)	Flood Peak at Mowat Probable Maximum (cumees)	Flood Peak at Mowat Probable Maximum (cumees)	Flood Peak at Mowat Probable Maximum (cumees)	Flood Peak at Mowat Probable Maximum (cumees)		Flood Peak at Mowat Probable Maximum (cumees)
1	High Peak Mowat	19.0	18.100	14.200	11.100	10.600	6.000	5.000	32.2	84.7	9.1	Yes	302	{ 42.1 % }	Reasonable control of floods throughout system and good irrigation yield. With high dead storage allows Jaxira Development.
2	Intermediate Fathia	27.8	15.000	10.000	9.900	10.000	22.500	15.000	34.3	90.3	11.2	No	347		Possibly higher than system 1
3	High Fathia	28.9	15.000	10.000	9.800	10.000	22.500	15.000	35.1	92.4	12.0	No	355	Probably higher than system 2	Excellent control of Baghdad floods and high irrigation yield. No control of Mowat floods and no Jaxira Development.
4	Low Peak Mowat and Low Fathia	{ 7.0 3.0 4.0 }	10.000	10.000	9.600	10.000	10.500	4.000	32.9	86.5	9.8	Yes	311	{ System 1 higher than }	Excellent control of floods throughout system and good irrigation yield. With High Peak Mowat dead storage allows Jaxira Development. Probably high cost.
5	High Peak Mowat and High Jaxira	26.8	15.800	12.400	9.700	10.600	6.000	5.000	35.2	92.6	12.1	Yes	311		90.9
6	Intermediate Fathia and High Jaxira	4.5	10.6	10.000	9.600	10.000	22.500	15.000	35.6	91.7	12.5	No	363	Undoubtedly high	Add comparatively small benefits to Intermediate Fathia alone. Addition of Fathia worthy of consideration only if power becomes important.

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- 17 Where two volumes are shown, these represent alternative or dual listings.
- 18 Not an listing - each of several fastidiously prepared and classified.
- 19 1976 - not entering.
- 20 1973 - not entering of Bookman of 111 16, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, 11th, 12th, 13th, 14th, 15th, 16th, 17th, 18th, 19th, 20th, 21st, 22nd, 23rd, 24th, 25th, 26th, 27th, 28th, 29th, 30th, 31st, 32nd, 33rd, 34th, 35th, 36th, 37th, 38th, 39th, 40th, 41st, 42nd, 43rd, 44th, 45th, 46th, 47th, 48th, 49th, 50th, 51st, 52nd, 53rd, 54th, 55th, 56th, 57th, 58th, 59th, 60th, 61st, 62nd, 63rd, 64th, 65th, 66th, 67th, 68th, 69th, 70th, 71st, 72nd, 73rd, 74th, 75th, 76th, 77th, 78th, 79th, 80th, 81st, 82nd, 83rd, 84th, 85th, 86th, 87th, 88th, 89th, 90th, 91st, 92nd, 93rd, 94th, 95th, 96th, 97th, 98th, 99th, 100th, 101st, 102nd, 103rd, 104th, 105th, 106th, 107th, 108th, 109th, 110th, 111th, 112th, 113th, 114th, 115th, 116th, 117th, 118th, 119th, 120th, 121st, 122nd, 123rd, 124th, 125th, 126th, 127th, 128th, 129th, 130th, 131st, 132nd, 133rd, 134th, 135th, 136th, 137th, 138th, 139th, 140th, 141st, 142nd, 143rd, 144th, 145th, 146th, 147th, 148th, 149th, 150th, 151st, 152nd, 153rd, 154th, 155th, 156th, 157th, 158th, 159th, 160th, 161st, 162nd, 163rd, 164th, 165th, 166th, 167th, 168th, 169th, 170th, 171st, 172nd, 173rd, 174th, 175th, 176th, 177th, 178th, 179th, 180th, 181st, 182nd, 183rd, 184th, 185th, 186th, 187th, 188th, 189th, 190th, 191st, 192nd, 193rd, 194th, 195th, 196th, 197th, 198th, 199th, 200th, 201st, 202nd, 203rd, 204th, 205th, 206th, 207th, 208th, 209th, 210th, 211st, 212nd, 213th, 214th, 215th, 216th, 217th, 218th, 219th, 220th, 221st, 222nd, 223rd, 224th, 225th, 226th, 227th, 228th, 229th, 230th, 231st, 232nd, 233rd, 234th, 235th, 236th, 237th, 238th, 239th, 240th, 241st, 242nd, 243rd, 244th, 245th, 246th, 247th, 248th, 249th, 250th, 251st, 252nd, 253rd, 254th, 255th, 256th, 257th, 258th, 259th, 260th, 261st, 262nd, 263rd, 264th, 265th, 266th, 267th, 268th, 269th, 270th, 271st, 272nd, 273rd, 274th, 275th, 276th, 277th, 278th, 279th, 280th, 281st, 282nd, 283rd, 284th, 285th, 286th, 287th, 288th, 289th, 290th, 291st, 292nd, 293rd, 294th, 295th, 296th, 297th, 298th, 299th, 300th, 301st, 302nd, 303rd, 304th, 305th, 306th, 307th, 308th, 309th, 310th, 311st, 312nd, 313th, 314th, 315th, 316th, 317th, 318th, 319th, 320th, 321st, 322nd, 323rd, 324th, 325th, 326th, 327th, 328th, 329th, 330th, 331st, 332nd, 333rd, 334th, 335th, 336th, 337th, 338th, 339th, 340th, 341st, 342nd, 343rd, 344th, 345th, 346th, 347th, 348th, 349th, 350th, 351st, 352nd, 353rd, 354th, 355th, 356th, 357th, 358th, 359th, 360th, 361st, 362nd, 363rd, 364th, 365th, 366th, 367th, 368th, 369th, 370th, 371st, 372nd, 373rd, 374th, 375th, 376th, 377th, 378th, 379th, 380th, 381st, 382nd, 383rd, 384th, 385th, 386th, 387th, 388th, 389th, 390th, 391st, 392nd, 393rd, 394th, 395th, 396th, 397th, 398th, 399th, 400th, 401st, 402nd, 403rd, 404th, 405th, 406th, 407th, 408th, 409th, 410th, 411st, 412nd, 413th, 414th, 415th, 416th, 417th, 418th, 419th, 420th, 421st, 422nd, 423rd, 424th, 425th, 426th, 427th, 428th, 429th, 430th, 431st, 432nd, 433rd, 434th, 435th, 436th, 437th, 438th, 439th, 440th, 441st, 442nd, 443rd, 444th, 445th, 446th, 447th, 448th, 449th, 450th, 451st, 452nd, 453rd, 454th, 455th, 456th, 457th, 458th, 459th, 460th, 461st, 462nd, 463rd, 464th, 465th, 466th, 467th, 468th, 469th, 470th, 471st, 472nd, 473rd, 474th, 475th, 476th, 477th, 478th, 479th, 480th, 481st, 482nd, 483rd, 484th, 485th, 486th, 487th, 488th, 489th, 490th, 491st, 492nd, 493rd, 494th, 495th, 496th, 497th, 498th, 499th, 500th, 501st, 502nd, 503rd, 504th, 505th, 506th, 507th, 508th, 509th, 510th, 511st, 512nd, 513th, 514th, 515th, 516th, 517th, 518th, 519th, 520th, 521st, 522nd, 523rd, 524th, 525th, 526th, 527th, 528th, 529th, 530th, 531st, 532nd, 533rd, 534th, 535th, 536th, 537th, 538th, 539th, 540th, 541st, 542nd, 543rd, 544th, 545th, 546th, 547th, 548th, 549th, 550th, 551st, 552nd, 553rd, 554th, 555th, 556th, 557th, 558th, 559th, 560th, 561st, 562nd, 563rd, 564th, 565th, 566th, 567th, 568th, 569th, 570th, 571st, 572nd, 573rd, 574th, 575th, 576th, 577th, 578th, 579th, 580th, 581st, 582nd, 583rd, 584th, 585th, 586th, 587th, 588th, 589th, 590th, 591st, 592nd, 593rd, 594th, 595th, 596th, 597th, 598th, 599th, 600th, 601st, 602nd, 603rd, 604th, 605th, 606th, 607th, 608th, 609th, 610th, 611st, 612nd, 613th, 614th, 615th, 616th, 617th, 618th, 619th, 620th, 621st, 622nd, 623rd, 624th, 625th, 626th, 627th, 628th, 629th, 630th, 631st, 632nd, 633rd, 634th, 635th, 636th, 637th, 638th, 639th, 640th, 641st, 642nd, 643rd, 644th, 645th, 646th, 647th, 648th, 649th, 650th, 651st, 652nd, 653rd, 654th, 655th, 656th, 657th, 658th, 659th, 660th, 661st, 662nd, 663rd, 664th, 665th, 666th, 667th, 668th, 669th, 670th, 671st, 672nd, 673rd, 674th, 675th, 676th, 677th, 678th, 679th, 680th, 681st, 682nd, 683rd, 684th, 685th, 686th, 687

[illegible][illegible]

development can be met by the full height of dam at these locations, by low dams at both Eski Mosul and Fatha, or by the addition of Bekhme to either of the two.

7.51 The justification for addition of Bekhme to either Eski Mosul or Fatha in the ultimate development is questionable. Bekhme adds very little benefit, at very high costs, when it is added to a high Fatha. When added to a high Eski Mosul, the benefits attributable to Bekhme are more significant, although it is doubtful whether the incremental benefits from Bekhme would justify its cost. Bekhme would be warranted in any ultimate scheme only if (a) power production became important, (b) large reservoirs were constructed in Turkey which would replace some of the regulation credited in our studies to Eski Mosul, or (c) it was considered imperative, in a system including Eski Mosul, to increase the firm irrigation yield above the 85 percent of maximum potential that is provided when the Jazira unit is included. For these reasons we have retained the Bekhme Dam as an alternative, combined with dams at either Eski Mosul or Fatha.

7.52 In their ultimate stages, a high Fatha Reservoir will develop more of the system potential than Eski Mosul (92.4 percent compared with 84.7 percent). These percentages are not an entirely comparable measure of the relative benefits, however, because about half of the difference is attributable to the addition of the Jazira unit to the high Eski Mosul, which, of course, is not possible with Fatha alone. If the high Eski Mosul alone were added to the existing system, without the Jazira unit, 88.7 percent of the system potential would be developed.

7.53 A choice between Fatha and Eski Mosul depends primarily upon (a) physical feasibility and cost of a dam at Fatha and (b) the desires of

the Iraq Government for flood protection and irrigation development in the Mosul area, which are possible only with the Eski Mosul Reservoir. Neither of these is known to us at present.

7.54 If flood protection or irrigation development in the Mosul area is not desired, Fatha is the best choice for both initial and ultimate development, providing the cost per milliard of increase in irrigation yield would not be greatly in excess of that of Eski Mosul. Some excess in cost would be justified because Fatha gives additional flood-control benefits. An exact measure of such allowable excess in costs is difficult to state, but certainly costs per milliard of yield at Fatha that are 25 percent in excess of those at Mosul would be very difficult to justify. If Fatha is built it would be desirable that it be constructed in stages, with a low dam initially, to be raised later to its ultimate elevation. However, we do not know whether this is possible.

7.55 On the other hand, if (a) flood protection and irrigation development are considered important or (b) Fatha is considered physically infeasible or excessive in cost, then Eski Mosul is clearly the better choice. It could be constructed initially to its low elevation and later raised to its ultimate elevation, with only a minor penalty in additional capital cost because of stage construction.

7.56 A low Eski Mosul and a low Fatha may be worthy of consideration. Such a combination would increase the annual firm irrigation yield by about one milliard over a high Eski Mosul, as well as allow irrigation development of the Jazira Project. However, this combination would have about two milliards less firm irrigation yield than a high Fatha. The combination would give more positive flood control than a high Eski Mosul and would add the benefits of flood protection at Mosul to the protection of

It is difficult
geologically
to raise
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Baghdad that would be available from a high Fatha alone. Cost estimates for Fatha will be necessary to determine whether these incremental benefits are worth the high incremental costs that undoubtedly would be involved.

7.57 There is much to be said for the selection of a low Eski Mosul Dam as the initial stage of development. This would provide flood protection for Mosul and would offer considerable flexibility to meet future alternative plans. The low Eski Mosul can (a) allow later development of the Jazira Project, (b) be raised to its ultimate height to develop about 85 percent of the maximum potential of the basin, (c) be combined with a low Fatha, or (d) be combined with Bekhme if power is found to be important or dams are constructed on the Tigris in Turkey.

Interim Use of Surplus Storage

7.58 An orderly development program will require that additional storage be provided as soon as the need arises. In such a program there will be an initial period, after construction of a new dam, in which available storage exceeds the irrigation need. This situation will recur each time additional storage is added to the system. The optimum use of the facilities will require that this surplus storage capacity be put to beneficial service.

7.59 There are several ways in which the temporary surplus storage capacity can be used. Some of the more prominent ones, not necessarily in order of importance, are as follows:

- a. Provide additional flood-control space
- b. Provide increased water deliveries for leaching purposes

- c. Temporarily increase the unit irrigation deliveries
- d. Provide increased flooding of rice lands
- e. Maintain higher minimum river flow to reduce pumping lifts, facilitate navigation, and improve the amenities of the river
- f. Increase minimum rate of power production.

7.60 The selected temporary use could be supplied even if a critically dry period should occur. There will always be additional surplus water during wetter periods. Some temporary uses can be met with certainty only for a few years, so it is important to avoid establishing "vested interests" in such uses that would preclude later use for the intended purpose.

7.61 The surplus storage capacity can be used for additional flood-control space very easily by lowering the flood-control rule curves. This is a very valuable function and is discussed for Dokan and Derbend-i-Khan reservoirs in Chapter 8.

7.62 Leaching of saline lands would be a very fitting use for the surplus storage capacity, provided sufficient drains have been constructed to make the leaching effective. The surplus storage capacity would permit continuous leaching even during dry years. There will of course be considerably more water available for this purpose in wet years.

7.63 A temporary increase in the unit irrigation deliveries should be approached with caution. An increase implies the delivery of more than normal needs; otherwise, the water could not be considered to be surplus. Excessive deliveries aggravate drainage problems. It has

been the general experience elsewhere that it is very difficult to return to normal delivery schedules after additional deliveries have been started.

7.64 Use of the surplus storage capacity to flood rice lands faces certain limitations. Outlet capacities of the reservoirs probably will preclude releases at a rate sufficient to increase the flooding materially unless control structures are constructed to divert the river water to the rice lands.

7.65 The surplus storage will permit a significant increase in the minimum flow of the river for the reduction of pumping lifts, improvement of navigation, and amenities of the river. The economic value of this use may be fairly low, but such benefits can be achieved incidental to other uses.

7.66 One of the most promising uses for the surplus storage is to increase the minimum flow for power purposes. This has been discussed in Chapter 6. The use of the surplus storage space to maintain higher minimum flows for power fits in well with all the uses listed above, except the added flood-control space and the increased flooding of rice lands.

CHAPTER VIII
RIVER CONTROL

Introduction
Streamflow Forecasting
Operating Rules and Guides
Operating Organization
Communications

Chapter 8

RIVER CONTROL

Introduction

Definition

8.1 Effective control of the rivers of Iraq is the ultimate objective of all the work covered in this report, including the collection of hydrologic data, the estimation of maximum floods and flood frequencies, and the conducting of operation studies. The application of accumulated information to the operation of the system requires integration of data on current supplies and demands into an operational plan as well as rapid communications and an efficient organization for river operation. This combination of technical, organizational, and operational activities is called "river control."

Requirements for Effective River Control

8.2 Efficient operation of the system will require a constant flow of data to a central control unit (which we will call here the River Control Center), a continual analysis of these data within this Center, and a continual outflow of operational instructions from the Center. The requirements for effective operation thus include the following:

- a. A continual flow to the River Control Center of information on water use and water-control requirements, including irrigation demands, flood situations, power loads, navigation needs, etc.

- b. A continual flow to the River Control Center of data on water availability, including streamflows, reservoir storages, canal flows, precipitation, and snow surveys.
- c. Estimates of future streamflows. These will be in two categories. Seasonal streamflow forecasts, based on precipitation and snow-survey data, will be required to schedule seasonal use of water and storage. In flood situations, daily forecasts of river flows, based on precipitation and streamflow reports, will be needed for flood-control operations.
- d. Rules and guides for preparation of operational plans.
- e. Facilities and technically trained personnel in the River Control Center to analyze effectively the data on water demands and supply and to determine flows needed to meet current situations, within the general rules and guides that have been established.
- f. Authority for the River Control Center to dispatch orders as required to widely dispersed field operating units with the assurance that these orders will be promptly and accurately carried out.
- g. A strict delineation of the authority of the field operating units and of the River Control Center. The objective in establishing such limits of authority should be to delegate the maximum authority possible to the local unit, while retaining within the River Control Center only that authority needed for effective coordination of overall operations.
- h. A rapid means of communication for transmittal of data and operational orders. The communication system must be dependable under storm and flood conditions, when it is most needed.

8.3 One of the most important requirements for effective operation of the system is the development of satisfactory forms for transmittal and

receipt of the data listed under items a, b, and c above. These data are required not only for efficient operation during a critical situation, but also for historical purposes, to allow subsequent analysis of operating procedures. They should be in orderly, convenient form, suitable for ready reference in critical operational situations. Copies of these data should be made available to all personnel involved in the development of operational decisions.

Current Data for Operations

8.4 The basic data needed by the River Control Center can be classified as either current or historical. The current data requirements, to be furnished to the Center as frequently as the current operational situation demands, comprise the following categories:

- a. Gage-height and discharge-measurement data from all key locations within the system. As a minimum, this information should include reservoir elevations and outflows, data from the lowest stream gage on each tributary and the key stream gages on the main stem of the Tigris, and flows in each irrigation canal offtake from the river or reservoirs. When available, reservoir inflows should also be included, although inflow can be computed from outflow and the change in storage.
- b. Precipitation and snow-survey data, including weather forecasts. During the non-flood season the transmittal of precipitation data can be at infrequent intervals, but during the flood season daily or more frequent reports should be received from key locations in the basin. Weather forecasts should be received as soon as available from the Iraq Meteorological Service.
- c. Information on water demands at each irrigation canal offtake, total power production required from each hydro-electric plant to meet power loads, flood situations at

critical locations, desires of navigation interests for maintenance of flows for navigation, desires of downstream users for rice flooding, and any other factor, such as pollution abatement or recreation, that might affect an operational situation.

Streamflow Forecasting

Types of Forecasts

8.5 Streamflow forecasting can be divided into daily forecasts and seasonal forecasts. Daily forecasts are needed only during flood situations and are used primarily for flood-control operations. Seasonal forecasts are desirable at all times of the year and are essential for effective scheduling of use of water for conservation purposes, particularly irrigation and power.

Daily Forecasts

8.6 Daily forecasts can be both quantitative and qualitative. Quantitative forecasts generally can be made only by routing upstream flows to a downstream point. In such routings, the procedures and constants given in the detailed description in Appendix B will be useful. Quantitative forecasting of changes in river flow is extremely difficult and costly when based on precipitation data alone and is justified in very few cases. In our opinion, the data available in Iraq are not adequate for such purposes, and the establishment in the near future of an elaborate system with this end in view is not justified.

8.7 Qualitative forecasts (for example, those predicting increases or decrease in flow but not the exact degree of change) are possible by use of current precipitation, snow-survey, and temperature data. Reports

of heavy precipitation can be used to indicate probable increases in streamflows. Similarly, increases or decreases in temperatures, interpreted along with periodic reports of snow surveys, can be used to indicate changes in streamflow due to snowmelt.

Seasonal Forecasts

8.8 Flood-season forecasts are possible because of the large time lag between the occurrence of snowfall, which accounts for a large part of the flood-season volume, and the resulting streamflow. Dry-season flow forecasts also may be possible from the volume of flood-season runoff, in which case a time lag also exists.

8.9 It is not yet evident what procedures will give the best seasonal forecasts for Iraq. There is not, at this time, a long enough period of record from recently established hydrologic installations for us to develop correlations between the data gathered and actual streamflows. Nevertheless, it is worthwhile to list five types of seasonal streamflow forecasts that have been used in other areas; these are as follows:

- a. Flood-season forecast from precipitation data,
- b. Flood-season forecast from snow-survey data,
- c. Flood-season forecast from combined precipitation and snow-survey data,
- d. Flood-season forecast from distribution graphs,
- e. Dry-season forecast from recession curves or correlations.

8.10 Variations of the above procedures are described in great detail in the annual Proceedings of the Western Snow Conference, United

States). We recommend that the River Control Center become a member of this organization, to obtain the annual publications as reference material. General approaches that may be used in these methods are discussed in the following paragraphs.

Forecasts Based on Precipitation Data

8.11 An advantage of this type of forecast is that data are already available for a number of years and forecasts can be made from time to time during the precipitation season. The disadvantage is that it is difficult or impossible to distinguish in the records between precipitation that occurs in violent rain storms, producing flood runoff, and precipitation that occurs as gentle rain or snow, with deferred runoff.

8.12 The Hydrological Survey devoted considerable effort toward devising forecasting procedures based on seasonal precipitation but concluded that the precipitation data were insufficient to produce usable procedures at the time. Another attempt should be made in a few years after sufficient data from the expanded meteorological network have been accumulated.

Forecasts Based on Snow Surveys

8.13 The measurement of snow depths and densities at strategically placed snow courses enables us to derive relationships between snow and subsequent runoff. Several years of snow-course data are required to derive a dependable relationship, but relative magnitudes of snow accumulation in different years will give a rough indication of streamflow from snowmelt even when the snow-course record is short. This type of forecast can be made from time to time throughout the period of snow accumulation. The best such forecast is that made just before the start of the major period of melting.

8.14 Since the records from the snow courses established by the Hydrological Survey are too short to permit derivation of a forecasting procedure at the present time, our recommendations are limited to suggestions to assist in the derivation of a procedure in the future. The procedure consists essentially of establishing a graphical relationship between (a) an index of the water equivalent of snow on a certain date each year and (b) streamflow during the next few months, for which the forecast is desired.

8.15 The most critical step is the choice of a suitable snow index. The determination of the average snow water-equivalent for a snow course for the date of the measurement has been described in Appendix A. This is the basic index value used in forecasting. The snow index for a specific date is determined from the water equivalent of all the courses in or near the river basin for which the forecast is desired. Various methods have been proposed for the weighting of individual courses, but this weighting should be done with caution. The snow courses established by the Hydrological Survey were well distributed both as to area and elevation; therefore, we recommend that the arithmetic average of the water-equivalent be used as the index until such time as the forecaster has acquired considerable skill.

8.16 It is important that the average for each year be for identical snow courses. Any missing records for a course used in determining the index must be estimated. The estimation procedure can best be described by an example using hypothetical data. Table 8-1 gives hypothetical values of water equivalent on or about 1 April for a group of snow courses. The problem is to estimate the missing 1 April figure for Course D for the year 1957. It is assumed that Courses A, B, and C

are all reasonably equidistant to Course D. It is found that the average value for water-equivalent for Courses A, B, and C for the years in which all data are available (1958 to 1961) is 6.1 inches. The relationship between average values for Course D and the other three courses therefore is $\frac{5.8}{6.1}$ or 0.95. The average water-equivalent for Course A, B, and C for 1 April 1957 is 7.9 inches. The estimated missing data for Course D for 1 April 1957 is therefore 0.95 times 7.9 inches or 7.5 inches.

Table 8-1

HYPOTHETICAL WATER EQUIVALENTS ON APRIL FIRST

(All values in inches)

Year	Course A	Course B	Course C	Course D	Total, Courses A, B, C	
1957	5.1	8.4	10.2	-	23.7	} Average value = 7.9 Four-year total = 73.3 Average value = $73.3 \div 12 = 6.1$
1958	3.2	6.1	6.0	4.7	15.3	
1959	4.6	7.1	9.5	7.3	21.2	
1960	5.7	9.2	10.8	7.5	25.7	
1961	2.1	4.8	4.2	<u>3.8</u>	11.1	
Four-year total = 23.3						
Average value = 5.8						

8.17 After the average snow water-equivalent has been determined for each year, the results are correlated with observed seasonal stream-flow. The relationship may be developed graphically or by statistical methods. A graphical method will be inherently as reliable as a statistical method until at least ten years of records are obtained. After that time a least-squares method will be most suitable. The correlation will never be perfect, since a simple relationship between snow water-content

and streamflow does not exist. However, the forecast procedures will allow prediction of the range of flows that may be expected.

Forecasts Based on Both Snow Surveys and Precipitation Data

8.18 Precipitation data and snow-survey data are frequently combined in the same forecasting procedure to increase the amount of data available. Where such data are available, this procedure is usually the best. However, the combination of data must be logical. Therefore, the physical significance of the data must be understood by the forecaster.

8.19 The usual procedure is to use accumulated precipitation during a specified period and snow water-content at the end of the period as the two principal forecasting parameters. The snow surveys provide an index of water in the basin on the date of measurement in the form of snow. Much of the water represented by the accumulated precipitation, however, has already left the basin as runoff or evapo-transpiration losses. The accumulated precipitation therefore represents water that has reached the basin, while the snow data represents water that has been retained in the basin. This form of forecast therefore usually contains a term for antecedent runoff to correct the forecast for water that has already passed through the system. A typical mathematical expression for such a forecast is as follows:

$$R = ax + by - cz + d,$$

where: R = Forecasted runoff, April through October;
 x = Snow water-content index, April 1;
 y = Index of November-through-March precipitation;
 z = November-through-March runoff;
 a , b , c , and d are constants.

The coefficients for such a procedure can best be evaluated by multiple-correlation computations.

8.20 At times, the multiple-correlation method has included temperature data or other factors by way of additional variables. In all such computations, the number of years of records necessary for reliable forecasts increases as the number of terms used in the procedure increases.

Forecasts by Distribution Graph

8.21 Snowmelt distribution graphs are somewhat similar in nature to unit hydrographs for runoff from precipitation. Where snowmelt is the predominant factor in producing flood-season runoff, it has been found that plots of cumulative seasonal runoff (expressed as a percentage of the total seasonal runoff) versus cumulative degree-days of temperature above the melting point will produce curves which are very similar in shape, regardless of the magnitude of the seasonal flow. The use of such curves as the snowmelt season progresses offers a good basis for evaluating the accuracy of forecasts made by other methods. This sort of check is especially important in reservoir operations, where the probable inflow must be continually evaluated as the season progresses. The applicability of this method obviously depends on the relative amounts of runoff originating from precipitation and snowmelt.

Dry-Season Forecasts

8.22 Forecasts of the amount of flow available in the low-runoff period can frequently be made by correlation between such flows and the seasonal flood inflows. Either direct correlation procedures or a recession-curve method can be used. When the snowmelt and the seasonal precipitation are essentially completed, the entire streamflow for the next few months will be derived from groundwater sources. The rate of streamflow on any date during this period provides an index of the amount of water

in ground storage on that date and therefore also provides an index of general groundwater streamflow for the next few months. This type of forecast cannot be made until fairly late in the season, a circumstance which greatly reduces its value for flood-season use. However, it can be useful for prediction of flow volumes in the dry season.

Operating Rules and Guides

General Recommendations

8.23 In the successful operation of any multiple reservoir system, it cannot be expected that definite rules and guides for meeting all eventualities can be established in advance. The possible combinations of streamflows, water requirements, and storage situations are too numerous to allow fully applicable plans to be developed beforehand for all situations. General rules and guides of real value can be developed, but a rigid set of rules purporting to be complete will inevitably result in waste of water or excessive flooding in certain unforeseeable situations that do not fit the general pattern.

8.24 The most desirable approach is to adopt general rules and guides which are known to be suitable for certain aspects of operations, at least for the initial stages of operations. As new situations arise, they would be studied by the River Control Center, and thus new and revised criteria would evolve. The general rules and guides should be periodically reviewed in the light of more recent records and operating experience, to determine whether revision is necessary.

Initial Operation of Proposed Reservoirs

8.25 As additional reservoirs are added to the system, there will for varying periods be storage capacity in excess of that needed for irrigation purposes. This extra capacity can be used for flood control until

irrigation demands have grown to the ultimate demand on the reservoir. Alternatively it can be used for increases in firm power, for navigation, or for rice flooding, all of which are discussed in Chapter 7.

8.26 The date at which additional reservoirs will be brought into operation is not known. In addition, the probable future requirements and relative importance of the alternative interim uses are matters not within the scope of our present assignment. Therefore, it is impossible at this time to make specific recommendations concerning rule curves to be used in the interim stage. At the time each reservoir nears the operational stage, further operational studies will have to be made and policy decisions concluded to determine a rule curve for interim use.

8.27 The rule curves shown on Exhibit 21 can be used as general guides in the derivation of rule curves for interim use. On the several graphs contained in this exhibit, those curves labeled "High dam, intermediate irrigation" and "Intermediate dam, low irrigation" are possibilities for interim uses of storage; results from system operating studies have been obtained for these curves.

Ultimate Operation of All Reservoirs

8.28 We recommend that ultimate operation of all reservoirs in any given system, after development of the full irrigation demands corresponding to the potential of the system, be controlled primarily by the rule curves of Exhibit 21. Within the limitations imposed by the uncertainties in the forecast of seasonal inflows, the River Control Center can in any given year lower the rule curve for the benefit of flood control in accordance with the forecast. Since the rule curve is based on assured refilling in the minimum historical period with tolerable irrigation shortages, the amount

by which the forecast (with adequate allowance for margin for error) exceeds the historical minimum can be used to determine the amount by which the rule curve can be lowered. It is generally assumed that there should be only about a five to ten percent chance taken that the reservoir will not refill. This probability can be computed from any of the mathematical forecast procedures suggested.

8.29 If policy decisions are made to maintain a higher minimum power production, navigation water supply, or rice flooding than is available by giving irrigation strict priority, then some adjustment in the rule curve may be necessary, or, alternatively, a new rule curve may have to be developed to reduce the storage capacity available for flood control.

8.30 We recommend, however, that the criteria for reservoir releases in the interest of flood control be as shown on Table 4-3.

Annual Operating Plan

8.31 An annual operating plan should be developed each year to chart a course of operations for the coming year. This plan should be developed prior to the flood season, in about February, and should show scheduled operations for the various conditions likely to arise during the following year. The plan should include provisions for changing from one scheme of operations to another, within predetermined limits, as the situation demands.

8.32 It has been found convenient in other systems to prepare a general plan showing the course of operations for streamflows of (a) median expectancy, (b) one-in-ten-chance expectancy on the high side of median expectancy, and (c) one-in-ten-chance expectancy on the low side of median. The annual plan, then, encompasses any number of possible courses of

action within a range delimited by the general plan. The range of operations may be defined in terms of reservoir storage, reservoir releases, or both. The streamflow expectancies used to define the limits of the range should be based on forecasted streamflows for as far into the future as is feasible. These forecasts are to be revised as historical data for the year become available. The water demands planned for should be based on the best current estimate of such requirements.

8.33 The annual operating plan will need revision each time a significant change in conditions of supply and demand becomes known. Experience will dictate the best time for such revisions; experience on other systems would indicate that at least two revisions per year are needed. These will be in the late spring, when snowmelt inflow and maximum reservoir storage are known, and in the autumn, after summer irrigation requirements are satisfied.

8.34 Within the limits of the annual operating plan or its subsequent revisions, day-to-day scheduling of storage releases will be necessary to meet the ever-changing conditions of water supply and of the various demands.

8.35 Since the anticipated supply and demand will change with each passing year, it will be necessary to have a new operating plan for each year.

Operating Organization

8.36 This section deals with the personnel requirements and their responsibilities, to assure that the reservoir system is operated at optimum efficiency. The proposed organization is discussed from a functional standpoint rather than an administrative one. It is expected

that the organization will have a gradual growth as the river control system increases in complexity. Recommendations for the eventual river control organization are included in general terms.

8.37 The functions of the operating organization will be (a) to collect streamflow, precipitation, and reservoir data, (b) to receive advance orders for irrigation requirements at key points in the river, (c) to evaluate the flood potential and seasonal streamflow potential, (d) to determine flows required for irrigation and other purposes, and (e) to issue orders for the operation of the control works at dams, barrages, and regulators. The operating organization should place an emphasis on the requirements for emergencies, and all operational procedures should be established with a view to efficient operation during an emergency.

8.38 Three distinct levels are contemplated for the operating organization. The top level is the policy level; the next is the technical level; and the third is the field level. The first and third levels are discussed briefly and the technical level in more detail in the following pages.

The Policy Control Officer and Advisory Committee

8.39 It is essential that the operating organization have a single responsible head. Policy control is a function of government, and therefore no recommendations are made concerning the selection of such an individual. He will be referred to hereafter merely as the Policy Control Officer.

8.40 The river control organization will be concerned with a very wide range of activities, and each activity will therefore have a direct bearing on overall water control policy. Therefore, we recommend that the Policy Control Officer be assisted by an advisory committee composed

of representatives from each agency having a significant interest in water control.

8.41 We recommend that the advisory committee hold regular meetings twice a year, with additional meetings when called by the Policy Control Officer. The main meeting should be held about the first of March to review the operating plan for the season of greatest flood potential and the subsequent summer drawdown period. Another meeting should be held about the first of November to review the plan for use of the water available during the winter drawdown period and to review operations in the preceding flood period with a view to improving future planning.

The River Control Center

8.42 The activities of the operating organization at the technical level should be performed by the group of technicians referred to herein as the River Control Center. This River Control Center should be located in Baghdad in order to be in touch with the Policy Control Officer. All important operating information and instructions should pass through this office, and the field activities relating to current hydrologic data and reservoir and barrage operations should be under its authority.

8.43 The River Control Center should function 24 hours a day, every day of the year, and should be in direct communication with all important field activities. This office should maintain up-to-the-minute records of streamflow at key points, snow data, reservoir content, gate settings at dams and barrages, and, during the flood season, precipitation at many key points. It should devise procedures for predicting streamflow at downstream points on the basis of streamflow at upstream

points. It should receive advance orders for irrigation flows required at key points and order appropriate gate openings at dams to provide the water when required. The office should devise procedures for forecasting seasonal streamflow and for predicting flood flows on the basis of precipitation and snowmelt as sufficient basis data become available. During a flood, it should continually make estimates of streamflow for the next few days and order releases at the dams and barrages to minimize flood damage. It should work out operating procedures well in advance for all foreseeable eventualities. It also should operate a reliable communications network between key points in the system.

8.44 The River Control Center should be headed by an individual, referred to hereafter as the River Control Officer, who should be the best hydrologist available. The position should carry sufficient salary and prestige to attract such an individual. He should be granted the greatest possible discretionary power within the established operating policy and should have direct access to the Policy Control Officer. He should be on call at all times during floods, and he or his senior assistant should be on call at all times during the season of possible floods. The River Control Officer will be the chief technical adviser to the Policy Control Officer. He will be responsible for preparing operating rules for all foreseeable eventualities for the approval of the Policy Control Officer and will also prepare periodic reports on past river operation.

8.45 It can be assumed that the military will play an important part in any emergency. The River Control Officer should maintain close liaison with the proper military officials at all times so that they will be familiar with the functions and responsibilities of his office and reduce confusion to a minimum in cases of emergency. Arrangements should

be made in advance for the use of military communications facilities in case of a breakdown in the river control network during an emergency.

8.46 The River Control Officer should have a thoroughly trained senior assistant capable of carrying out the duties of the River Control Officer if the latter should be incapacitated. In addition, there should be enough subprofessional personnel to perform all the processing of data. The staff should also include technicians to operate and maintain the communications network. None of the personnel should be permitted to take vacations during periods of possible floods.

Field Offices

8.47 It is expected that most of the river control functions of the field offices will be handled as collateral duties, so there must be a very clearly defined understanding between the River Control Center and the agency administering the field office as to its responsibilities to the River Control Center. These field offices should include the operating staffs at each of the dams and barrages and possibly the major irrigation offices. Each of these offices should serve as a collection center for hydrologic data in its area and should forward them immediately to the River Control Center. The staffs at the dams and barrages should take orders from the River Control Center regarding water releases and the collection and forwarding of hydrologic data.

8.48 The field office that operates the Samarra Barrage and Regulator warrants special mention. This is the key point for the protection of Baghdad in case of flood, and the official in charge of the office should be considered to be a deputy of the River Control Officer. He should receive up-to-the-minute reports on the flow of the Adhaim River and should be

capable of taking independent action on the division of the Tigris flow between the river and the Wadi Tharthar diversion in case of a complete failure of communications with the River Control Center.

Communications

8.49 We recommend that the River Control Center operate its own communications network to collect hydrologic and other operating data and to send operating instructions to the field offices. The same network should be used for both purposes insofar as is possible. The network should be designed to operate satisfactorily under emergency conditions; therefore, all important links should be by radio, and equipment should be duplicated. There should be a complete standby power supply, which should be used in normal communications at least once each week to assure their being in operating condition in an emergency.

8.50 Each field office should collect up-to-the-minute hydrologic data from all important nearby streamflow and precipitation stations. The office staff should do so by the most expeditious method available in each particular case. It is recommended that river gages of the telemark or telemeter type be gradually installed at all important streamflow stations. A telemark gage consists of an electrical device connected to a telephone circuit; the gage is reached by telephone in the same manner as a normal telephone would be, and it indicates the river gage height by an audible coded signal. A telemeter gage is similar except that it makes a continuous trace of gage height on a chart at a remote point, such as the field office. The telephone lines from the field offices to these gages should be carefully constructed to avoid failure during emergencies.

8.51 There should be at least one radio-broadcasting rain gage broadcasting to the appropriate field office from a strategic location in the catchment area of each reservoir and major tributary. These gages broadcast a signal at regular intervals, giving the amount of precipitation since the last signal. Such systems usually require line-of-sight reception; thus the broadcasting and receiving stations and any required relay stations must be very carefully placed. Priority for these installations should be given to uncontrolled areas, particularly on the Adhaim and the Diyala below Derbend-i-Khan.

8.52 Each field office should transmit the hydrologic data and other operating data from its particular area to the River Control Center in Baghdad according to a prearranged schedule. Once-a-day transmittal will be adequate for normal conditions, but this should be increased to several transmittals a day immediately preceding and during floods. The schedule should be so arranged that only one field office is communicating with the River Control Center at any one time.

8.53 The design, installation, and maintenance of communications networks is a specialized activity, remote from the field of hydrology. Therefore, we recommend that arrangements be made between the River Control Center and an agency of the government experienced in communications to design and install the network, to set the standards for routine maintenance, and to perform periodic inspection and major maintenance.

MAIN REPORT

EXHIBITS

1. Expansion Program, Stream Gaging and Sediment Sampling
2. Snow Survey Program
3. Expansion Program, Meteorological Network
4. Photographs
5. Analysis of Stream-Gaging Data
6. Probable Maximum Floods, Tigris River Basin
7. Probable Maximum Precipitation, Tigris River Basin
8. Drainage Sub-Basins and Mean Annual Precipitation, Tigris River Basin
9. Tigris River Basin Retention Rates
- 10a. Synthetic Unit Hydrograph Relations
- 10b. Tigris River Basin Unit Hydrographs
11. Snow Data, Area-Elevation Curves, and Basin Topography
12. Peak Frequency Curve Derivation
13. Effect of Reservoirs on Flood Peaks Below Reservoirs
14. Effect of Reservoirs on Flood Peaks at Samarra and Downstream
15. Flood Control Operation, Existing System
16. Flood Control Operation, Existing System Plus High Eski Mosul
17. Flood Control Operation, Existing System Plus High Bekhme
18. Flood Control Operation, Existing System Plus High Eski Mosul and High Bekhme
19. Flood Control Operation, Existing System Plus High Batna
20. Regulated Flood Peaks at Samarra and Downstream
21. Reservoir Volumes, Discharge Capacities, and Rule Curves
22. Schematic Diagram of Tigris River Irrigation System
23. Yield of Reservoirs in Tigris River Basin for Irrigation
24. Water Losses in Tigris River Basin, 1929-1937
25. Mass Diagram, Excess Tigris River Flow, 1980 Conditions
26. Irrigation Operation Study, Existing Reservoir System
27. Irrigation Operation Study, Existing Reservoir System Plus Low Eski Mosul
28. Irrigation Operation Study, Existing Reservoir System Plus High Eski Mosul and High Bekhme
29. Duration of Flow at Dokan and Derbend-i-Khan
30. Effect of Minimum Samarra Flow for Power on Irrigation Delivery

STREAM GAGING STATIONS

NAME OF STATION	CLASSIFICATION	1956	1957	1958	1959	MAJOR WORK
Tigris at Tusan	New					Class I cableway, gage well
Tigris at Falha	Improved					Class II cableway, gage well
Khabour near Zakho	Improved					Class I cableway, gage well
Greater Zab near Irtaz	New					Class II cableway, gage well
Swanduk at Urdin	Improved					Class II cableway, gage well
Khabour at Marquba	Improved					Reconstruct Class II cableway, gage well
Lesser Zab at Bahan	New					Class I cableway, gage well
Adhnam at Harra	Improved					Reconstruct Class II cableway, gage well
Diyala at Derbendi-Khan	New					Class II cableway, gage well
Balikh at Balikh	New					Reconstruct Class II cableway, gage well

SEDIMENT SAMPLING STATIONS

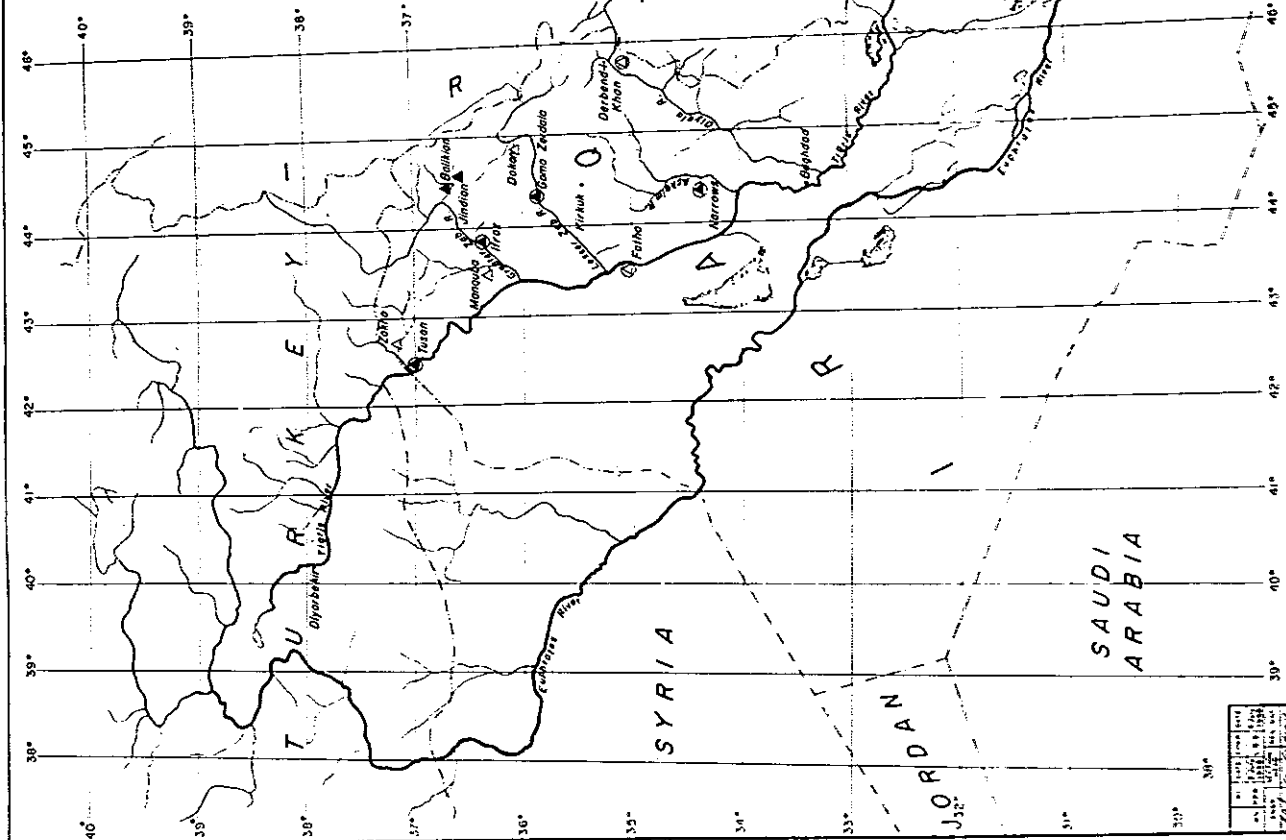
Tigris at Tusan	
Tigris at Falha	
Greater Zab near Irtaz	
Lesser Zab at Gama Zaidia	
Adhnam at Harra	
Diyala at Derbendi-Khan	

NOTE:

Above tabulation includes only those stations constructed or operated under direction of H.S.I. Stations operated by D.G.I. are not included except where construction work under direction of H.S.I. is indicated. Gage well at Derbendi-Khan will be constructed later under direction of Resident Engineer.

LEGEND

- Construction period
- Operation by H.S.I.
- Improved or rehabilitated station
- New station
- Sediment sampling station
- D.G.I. Director General of Irrigation



GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ
EXPANSION PROGRAM
STREAM GAGING AND
SEDIMENT SAMPLING
UNIVERSITY OF ILLINOIS, URBANA, ILL.
CHICAGO, ILL.
DATE: 10/1/59
610-14

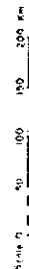
BASIN AND COURSE	Elevation		Year			
	Metres	Feet	1956	1957	1958	1959
GREATER ZAB BASIN			J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D			
Qamar Thagel	2540					
Kakresh	2310					
Kerkeshin	1900					
Chur Thagel	2100					
Daur Thagel	1810					
Sambawatal	820					
Gora Alpina	820					
Newesthah	1525					
Gunda Nowandi	1100					
G. ZAB / TIGRIS BASIN						
Chakli Townash	1685					
Ken Shagel	1720					
Ken Shagel	1790					
LESSER ZAB BASIN						
Salarah	1890					
Nurita	1340					
Habro	1250					
Agan Momak	1690					
Molabaw	1400					
Awil	1520					
Dawil Teleschen	1290					
DIVALA BASIN						
Kora Kzow	1780					
Harnecia	1620					
Harnecial Su	1480					
Dowlasur	890					
TIGRIS AND EUFRATES BASIN IN TURKEY						
TIGRIS BASIN IN IRAN						

20-25 Courses proposed

8-10 Courses proposed

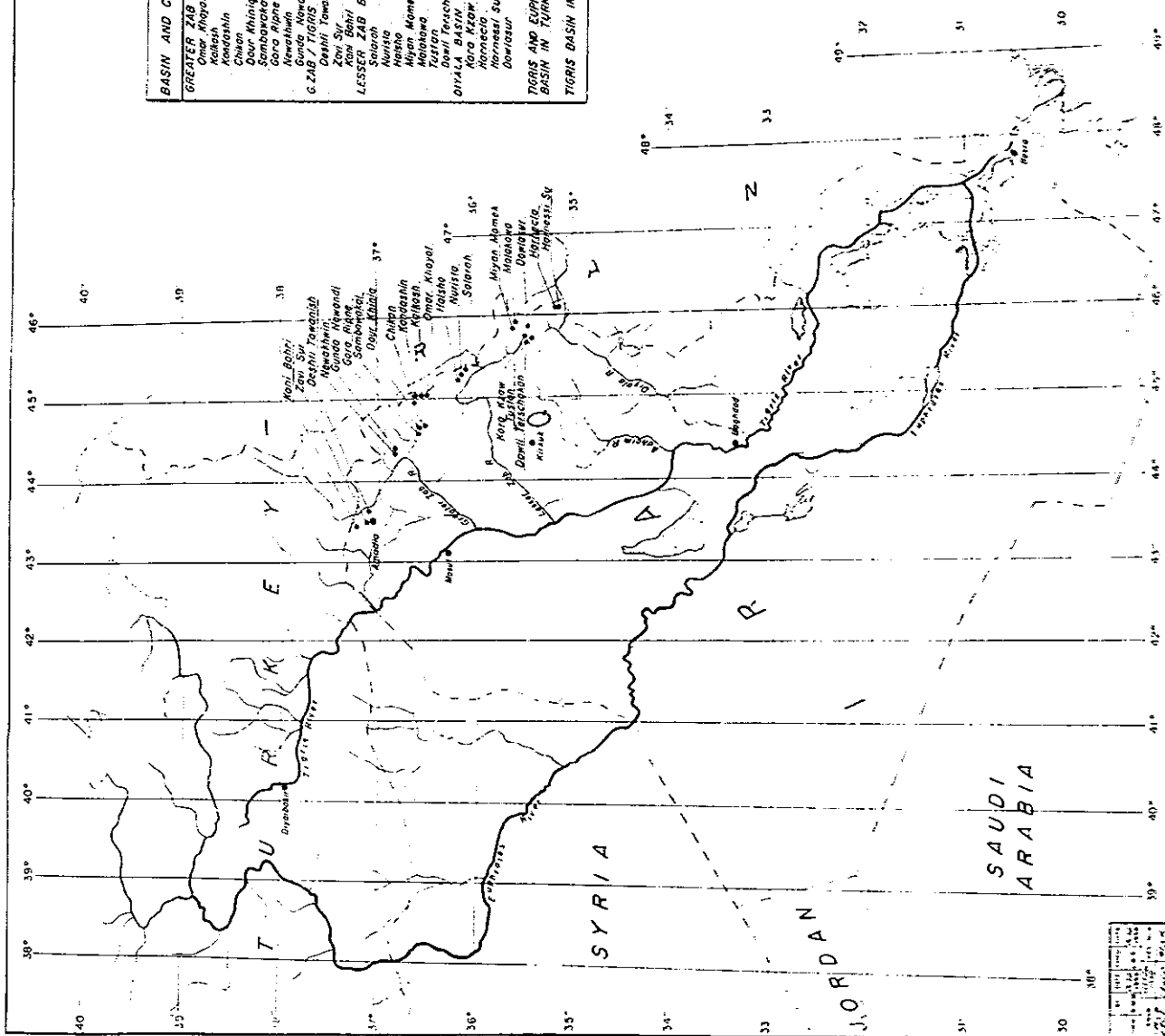
1. Courses are surveyed on the first and fifteenth of each month beginning on February 1 and ending on April 1 or May 1 inclusive.
2. Many courses are on basin divides and should prove to be of use for forecasting flows in basins other than those under which they are shown

	instigation of courses	Solar surveys observed
1960-1961	1	1
1961-1962	1	1
1962-1963	1	1
1963-1964	1	1
1964-1965	1	1
1965-1966	1	1
1966-1967	1	1
1967-1968	1	1
1968-1969	1	1
1969-1970	1	1
1970-1971	1	1
1971-1972	1	1
1972-1973	1	1
1973-1974	1	1
1974-1975	1	1
1975-1976	1	1
1976-1977	1	1
1977-1978	1	1
1978-1979	1	1
1979-1980	1	1
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1981-1982	1	1
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1985-1986	1	1
1986-1987	1	1
1987-1988	1	1
1988-1989	1	1
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1990-1991	1	1
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2000-2001	1	1
2001-2002	1	1
2002-2003	1	1
2003-2004	1	1
2004-2005	1	1
2005-2006	1	1
2006-2007	1	1
2007-2008	1	1
2008-2009	1	1
2009-2010	1	1
2010-2011	1	1
2011-2012	1	1
2012-2013	1	1
2013-2014	1	1
2014-2015	1	1
2015-2016	1	1
2016-2017	1	1
2017-2018	1	1
2018-2019	1	1
2019-2020	1	1
2020-2021	1	1
2021-2022	1	1
2022-2023	1	1
2023-2024	1	1
2024-2025	1	1
2025-2026	1	1
2026-2027	1	1
2027-2028	1	1
2028-2029	1	1
2029-2030	1	1
2030-2031	1	1
2031-2032	1	1
2032-2033	1	1
2033-2034	1	1
2034-2035	1	1
2035-2036	1	1
2036-2037	1	1
2037-2038	1	1
2038-2039	1	1
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2040-2041	1	1
2041-2042	1	1
2042-2043	1	1
2043-2044	1	1
2044-2045	1	1
2045-2046	1	1
2046-2047	1	1
2047-2048	1	1
2048-2049	1	1
2049-2050	1	1
2050-2051	1	1
2051-2052	1	1
2052-2053	1	1
2053-2054	1	1
2054-2055	1	1
2055-2056	1	1
2056-2057	1	1
2057-2058	1	1
2058-2059	1	1
2059-2060	1	1
2060-2061	1	1
2061-2062	1	1
2062-2063	1	1
2063-2064	1	1
2064-2065	1	1
2065-2066	1	1
2066-2067	1	1
2067-2068	1	1
2068-2069	1	1
2069-2070	1	1
2070-2071	1	1
2071-2072	1	1
2072-2073	1	1
2073-2074	1	1
2074-2075	1	1
2075-2076	1	1
2076-2077	1	1
2077-2078	1	1
2078-2079	1	1
2079-2080	1	1
2080-2081	1	1
2081-2082	1	1
2082-2083	1	1
2083-2084	1	1
2084-2085	1	1
2085-2086	1	1
2086-2087	1</	



GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
BAGHDAD, IRAQ

SNOW SURVEY PROGRAM

[illegible]

River sub-basin	No. of Installations		1956		1957		1958		1959	
	WPP, No.	Preced. Proj.	JFMAMJJASOND	Evap.	JFMAMJJASOND	Evap.	JFMAMJJASOND	Evap.	JFMAMJJASOND	Evap.
River sub-basin										
Tigris main stem in Iraq	2	3	1							
Tigris in Turkey *	11	6	0							
Graoter Zab in Iraq	6	3	1							
Lesser Zab in Iraq	4	1	1							
Lesser Zab in Iran *	3	1	0							
Adhaim in Iraq	2	2	0							
Diyala in Iraq	3	3	0							
Diyala in Iran *	7	2	0							
Euphrates in Turkey *	12	11	0							
Euphrates in Iraq	0	3	0							

LEGEND

- | Actual or scheduled installation | Actual operation |
|---|------------------|
| Proposed nonrecording precipitation gage | |
| Proposed recording precipitation gage | |
| Nonrecording precipitation gage installed | |
| Recording precipitation gage installed by H.S.I. | |
| Thermograph installed by H.S.I. | |
| Recording precipitation gage with temperature sensor | |
| Evaporation station installed by H.S.I. (if gage and temperature) | |

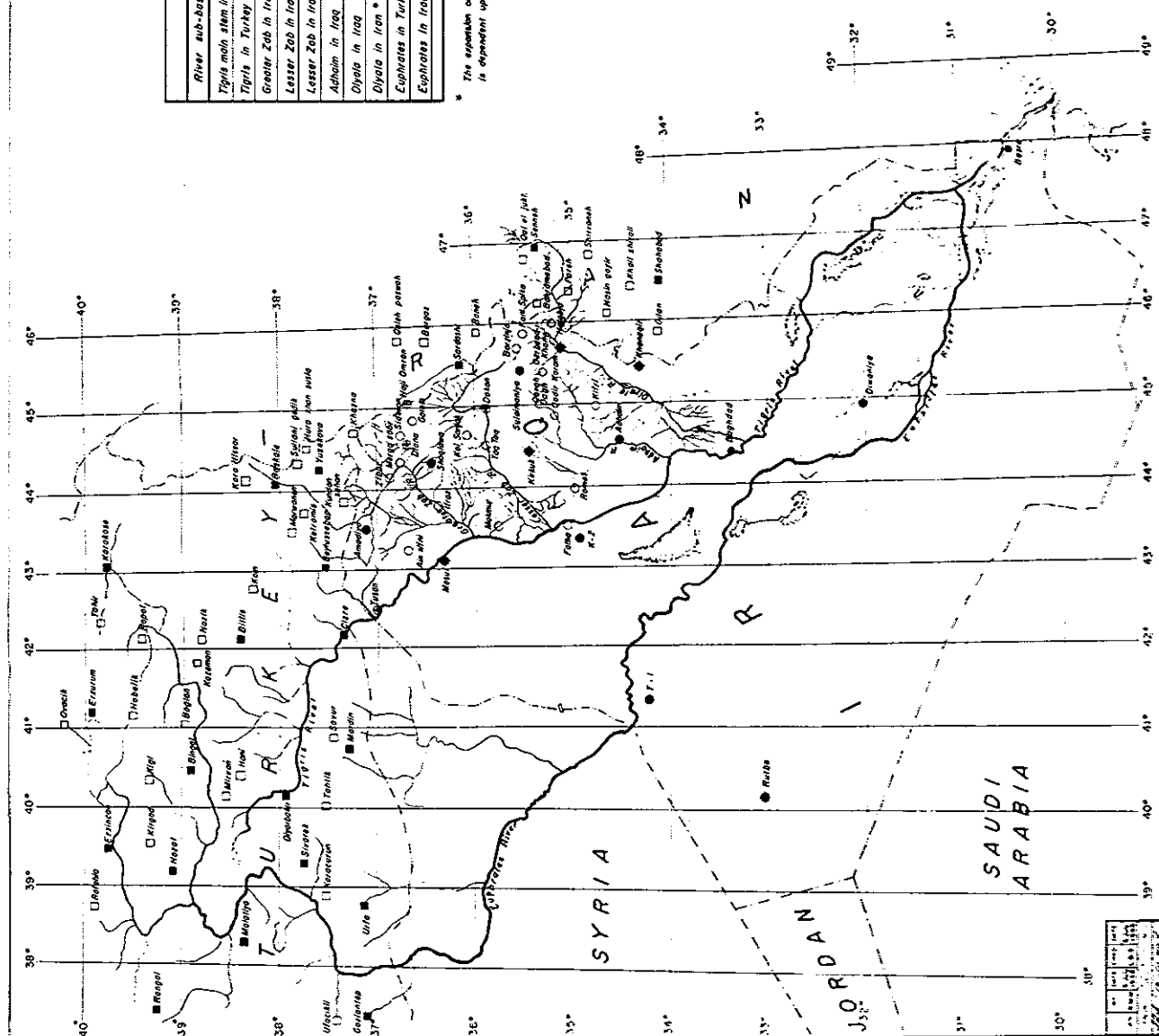
Map shows only the stations installed or proposed by U.S.I. Stations previously installed by meteorological services of Iraq and other countries are not shown.

Figure 10. 0 50 100 150 200 mm

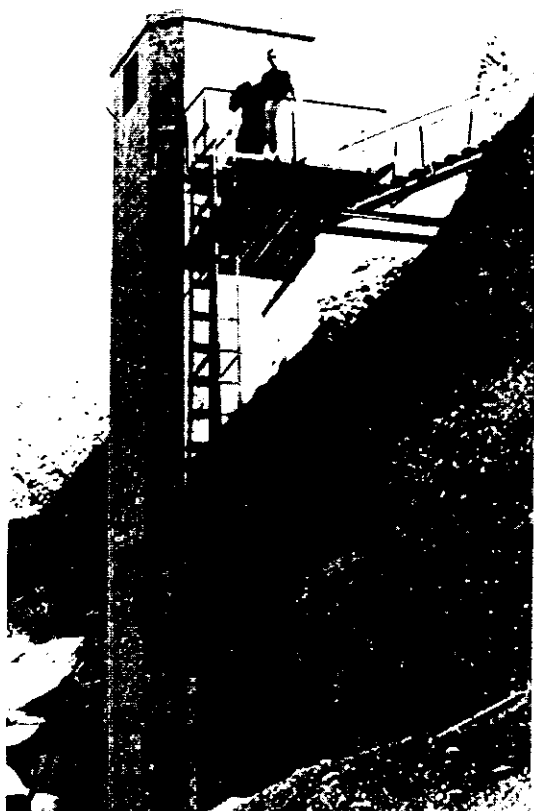
GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ
EXPANSION PROGRAM
METEOROLOGICAL NETWORK

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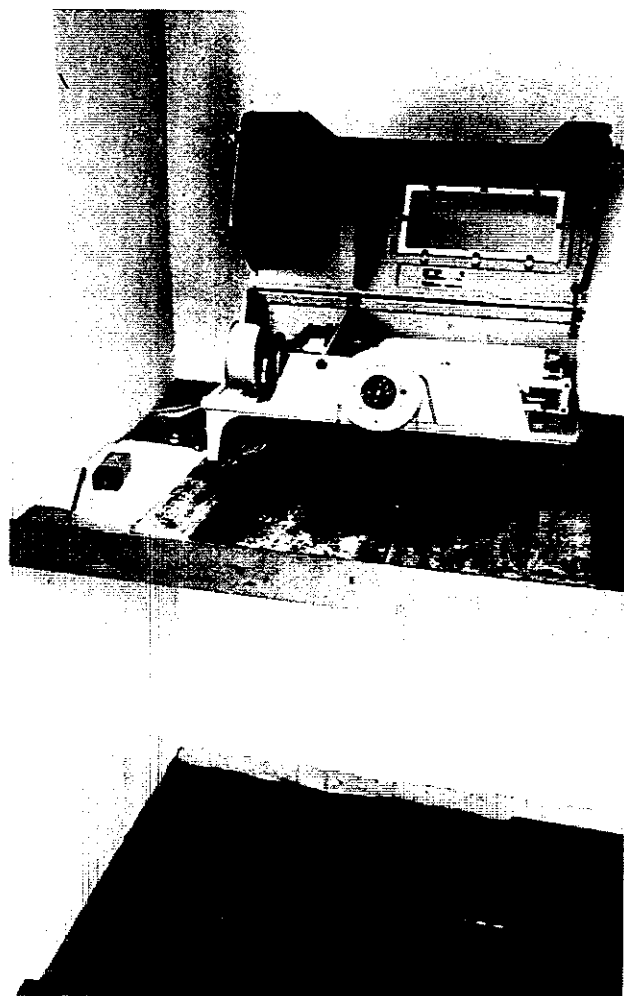
DATE	DESCRIPTION	AMOUNT	BALANCE
1980	1	100.00	100.00
1981	1	100.00	200.00
1982	1	100.00	300.00
1983	1	100.00	400.00
1984	1	100.00	500.00
1985	1	100.00	600.00
1986	1	100.00	700.00
1987	1	100.00	800.00
1988	1	100.00	900.00
1989	1	100.00	1000.00
1990	1	100.00	1100.00
1991	1	100.00	1200.00
1992	1	100.00	1300.00
1993	1	100.00	1400.00
1994	1	100.00	1500.00
1995	1	100.00	1600.00
1996	1	100.00	1700.00
1997	1	100.00	1800.00
1998	1	100.00	1900.00
1999	1	100.00	2000.00
2000	1	100.00	2100.00
2001	1	100.00	2200.00
2002	1	100.00	2300.00
2003	1	100.00	2400.00
2004	1	100.00	2500.00
2005	1	100.00	2600.00
2006	1	100.00	2700.00
2007	1	100.00	2800.00
2008	1	100.00	2900.00
2009	1	100.00	3000.00
2010	1	100.00	3100.00
2011	1	100.00	3200.00
2012	1	100.00	3300.00
2013	1	100.00	3400.00
2014	1	100.00	3500.00
2015	1	100.00	3600.00
2016	1	100.00	3700.00
2017	1	100.00	3800.00
2018	1	100.00	3900.00
2019	1	100.00	4000.00
2020	1	100.00	4100.00
2021	1	100.00	4200.00
2022	1	100.00	4300.00
2023	1	100.00	4400.00
2024	1	100.00	4500.00
2025	1	100.00	4600.00
2026	1	100.00	4700.00
2027	1	100.00	4800.00
2028	1	100.00	4900.00
2029	1	100.00	5000.00
2030	1	100.00	5100.00
2031	1	100.00	5200.00
2032	1	100.00	5300.00
2033	1	100.00	5400.00
2034	1	100.00	5500.00
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2036	1	100.00	5700.00
2037	1	100.00	5800.00
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2045	1	100.00	6600.00
2046	1	100.00	6700.00
2047	1	100.00	6800.00
2048	1	100.00	6900.00
2049	1	100.00	7000.00
2050	1	100.00	7100.00
2051	1	100.00	7200.00
2052	1	100.00	7300.00
2053	1	100.00	7400.00
2054	1	100.00	7500.00
2055	1	100.00	7600.00
2056	1	100.00	7700.00
2057	1	100.00	7800.00
2058	1	100.00	7900.00
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2061	1	100.00	8200.00
2062	1	100.00	



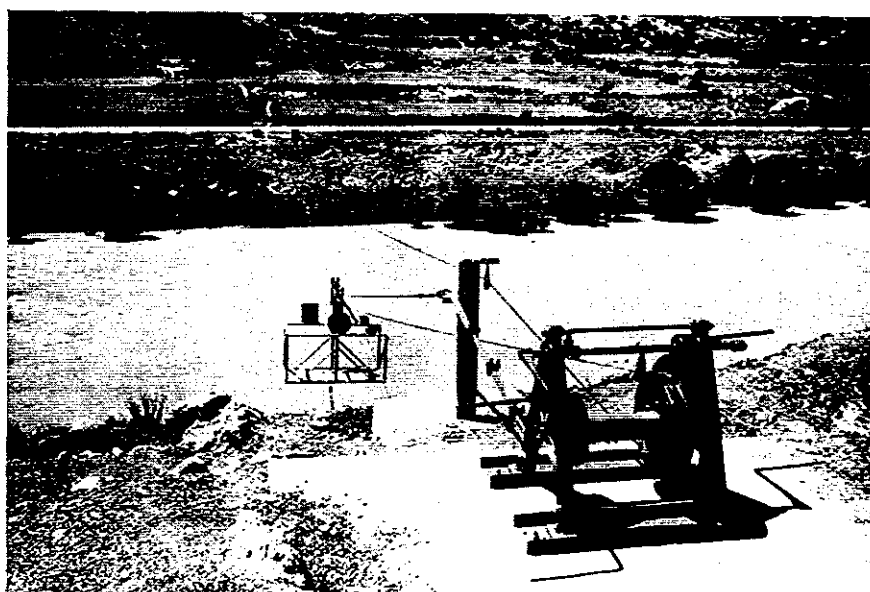
BEST AVAILABLE COPY



THE GAGE TOWER AT IFRAZ, GREATER ZAB RIVER (EXTERNAL STAFF GAGE NOT INSTALLED AT TIME OF PHOTO)



WATER STAGE RECORDER IN GAGE HOUSE



CLASS II CABLEWAY-RUWANDUZ RIVER AT JINDIAN

STREAM GAGING



DEEP ACCUMULATIONS OF SNOW IN THE IRAQ
MOUNTAINS (FEBRUARY 1957) HAJJI UMRAN

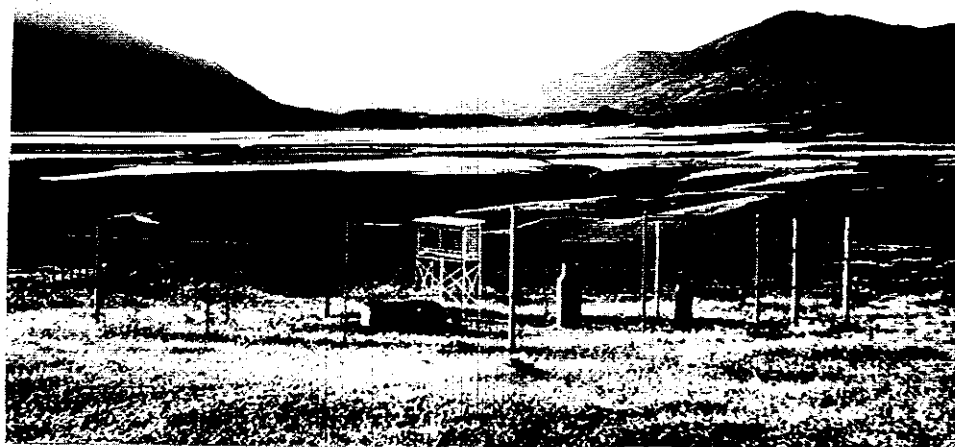


WEIGHING A SNOW SAMPLE

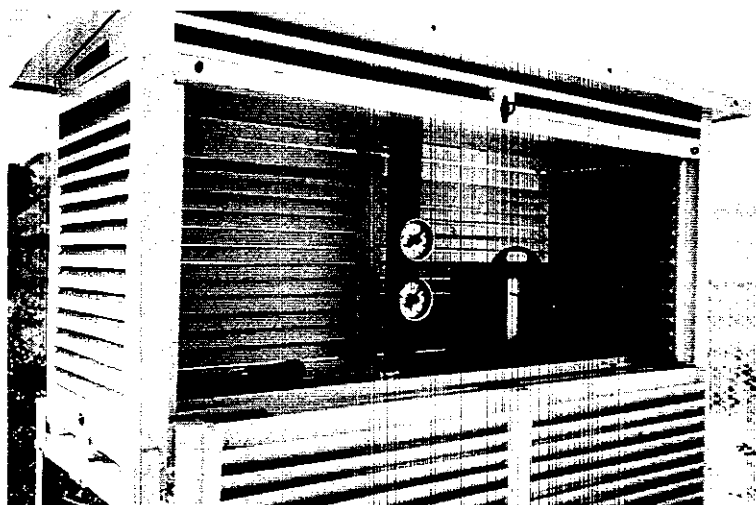


TAKING A SNOW SAMPLE

SNOW SAMPLING



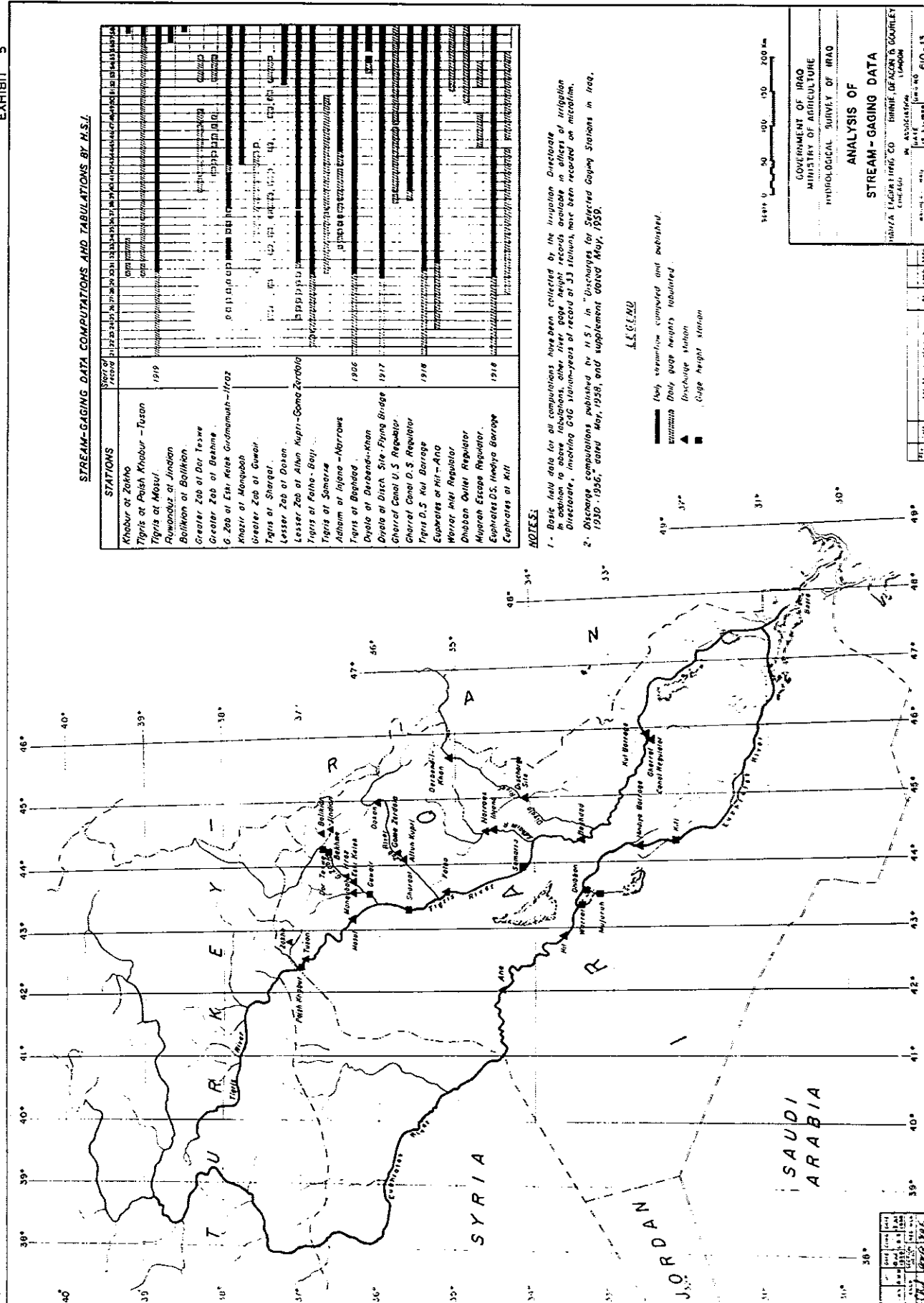
EVAPORATION STATION, DIANA, SHOWING ANEMOMETER AND
EVAPORATION PAN, THERMOMETER SCREEN, RECORDING RAIN
GAGE, AND NON-RECORDING RAIN GAGE

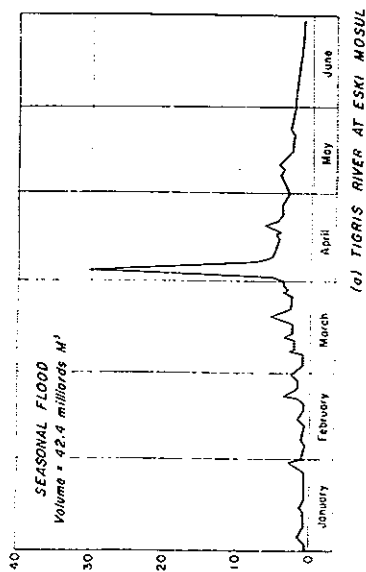


INTERIOR OF STEVENSON SCREEN, DIANA,
SHOWING SLING PSYCHROMETER, DIAL-TYPE
THERMOMETER, AND THERMOGRAPH

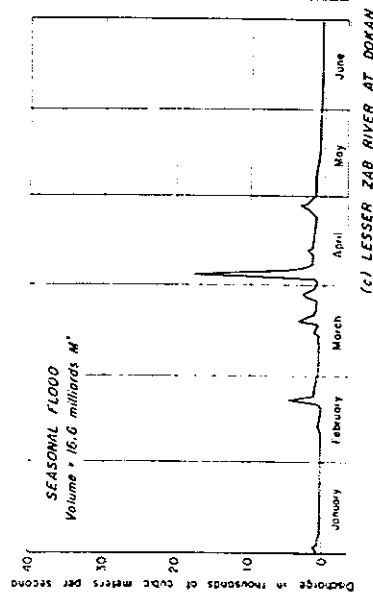


RECORDING RAIN GAGE

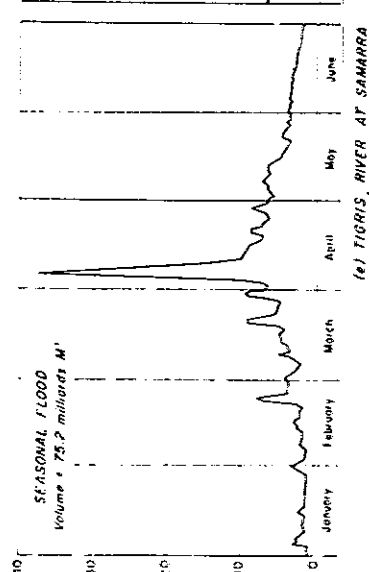




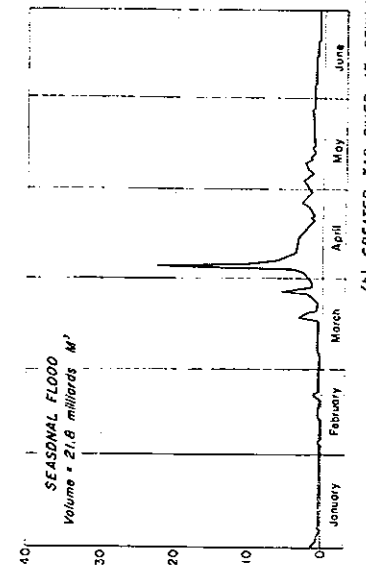
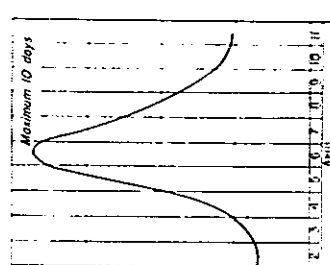
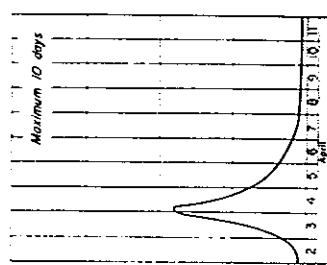
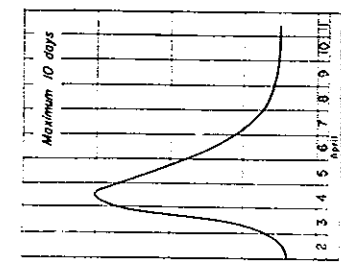
(a) TIGRIS RIVER AT ESKI MOSUL



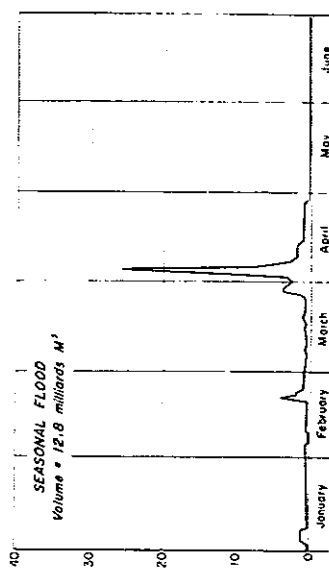
(c) LESSER ZAB RIVER AT DOKAN



(e) TIGRIS RIVER AT SAMARRA



(b) GREATER ZAB RIVER AT BEKHME



(d) DIYALA RIVER AT DERBEND-I-KHAN

NOTES.

1. Hydrographs shown represent natural, uncontrolled floods
2. Additional probable maximum floods, for which hydrographs are not shown, have been developed, as follows

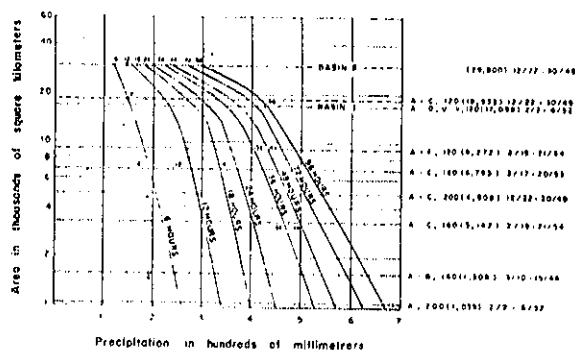
Region	Flood Peaks (cubic meters per second)
Central Tigris River, between Eski Mosul, Basrah, Uzun and Samarra dam sites	11,000
Adhram River at its mouth	13,000
Lower Diyala River, between Derbend-I-Khan Dam and mouth of Diyala	11,000
Tigris River at Baghdad	34,000
Tigris River below mouth of Diyala River	40,000

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

PROBABLE MAXIMUM FLOODS
TIGRIS RIVER BASIN

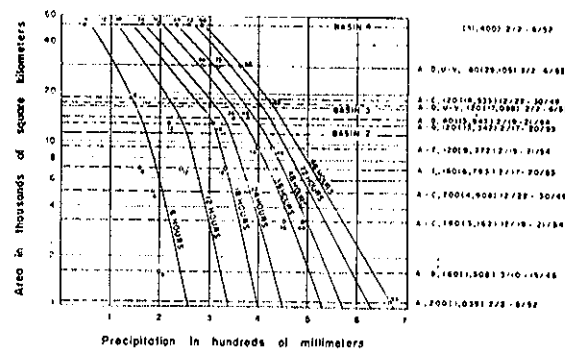
IRRA/CA INQUIRY FORM, CO. THINNET, OF KAZAN R. COURTESY
FOR DATA IN ASSASSIATION LONDON
DATE 1 Aug 1955
PAGE NO. 627-14

BEST AVAILABLE COPY



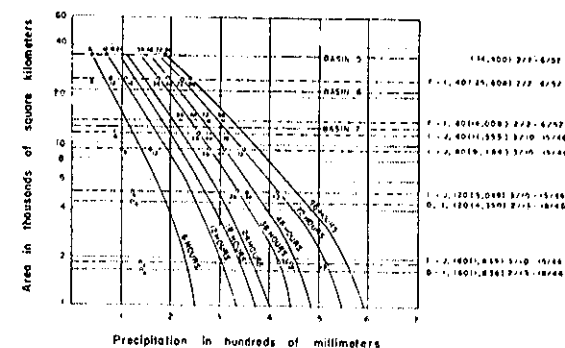
(a)

1. DIYALA RIVER ABOVE DERBEND-I-KHAN DAM
8. DIYALA RIVER ABOVE DIYALA WEIR



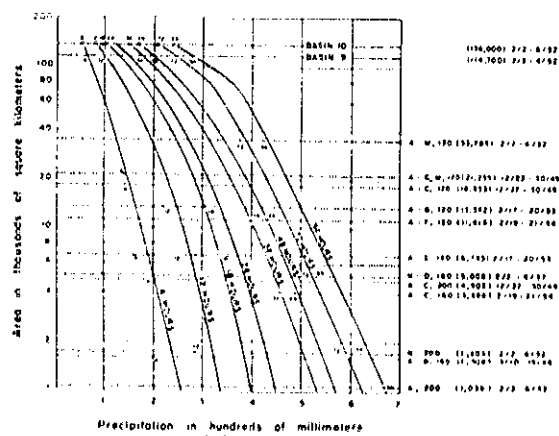
(b)

2. LESSER ZAB RIVER ABOVE DOKAN DAM
3. GREATER ZAB RIVER ABOVE BEKHME DAM SITE
4. TIGRIS RIVER ABOVE ESKI MOSUL DAM SITE



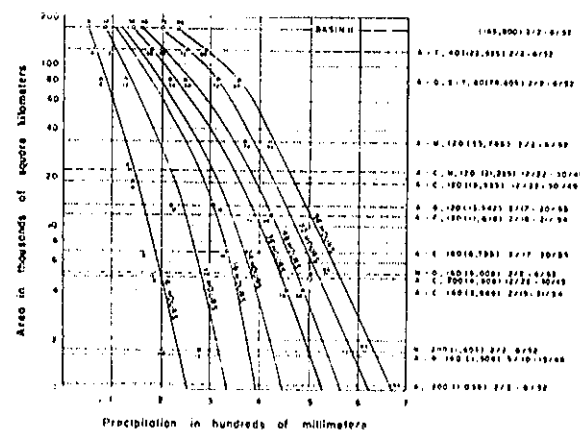
(c)

7. DIYALA R. BETWEEN DERBEND-I-KHAN DAM AND DIYALA WEIR
6. ADHAIM RIVER AT ITS MOUTH
5. CENTRAL TIGRIS (BELOW ESKI MOSUL, DOKAN, AND BEKHME
BUT ABOVE SAMARRA)



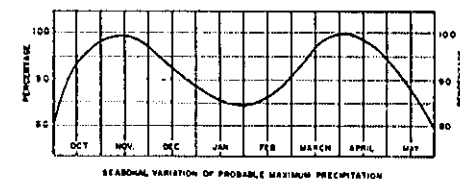
(d)

9. TIGRIS RIVER ABOVE SAMARRA
10. TIGRIS RIVER ABOVE BAGHDAD



(e)

- ## II. TIGRIS RIVER ABOVE AND INCLUDING DIYALA RIVER



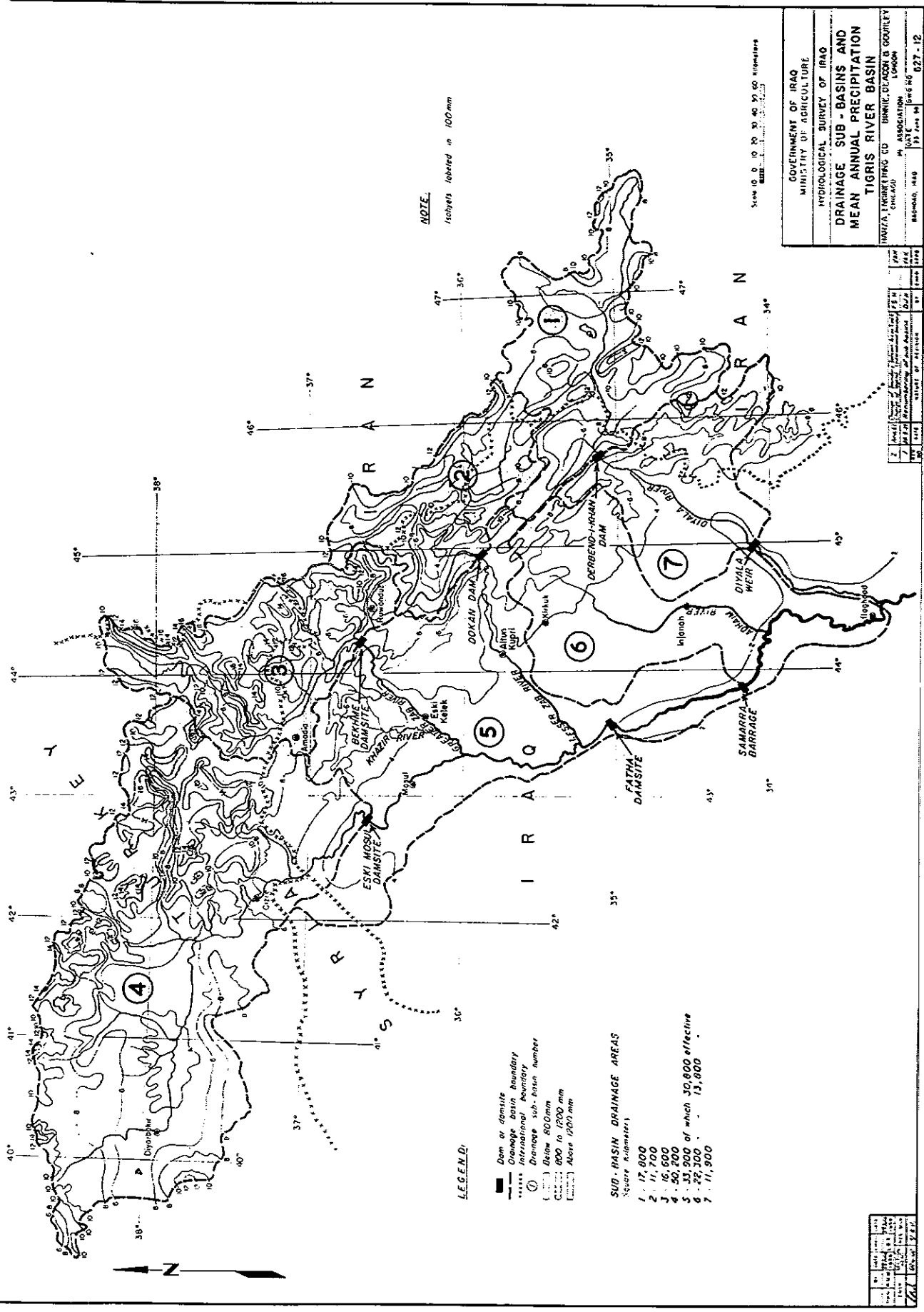
NOTE

1 Notations to right of grids identify maximized historical storm from which plotted points were obtained.
Following example gives the key for second from top horizontal dashed line of grid (e).

2-2-6/252	Date (Feb 2-6, 1952) of maximized historical storm
6" 12" etc	Maximized precipitation for 6, 12 etc hours durations of storm
1-1-7	Station center used to determine precipitation
	Lowest isohyet (in mm) included
122,555	Area encompassed by lowest isohyet (in sq mi.)

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ
PROBABLE MAXIMUM PRECIPITATION
TIGRIS RIVER BASIN

MAIL/PA INDEXED FROM: 100 SUBJECT: (H) ACCR IN COMB 100
(H) (H) LONGHORN
IN ABSENCE DATE NAME NO 627-11
ADDRESS: 1000 1 JAN 1966



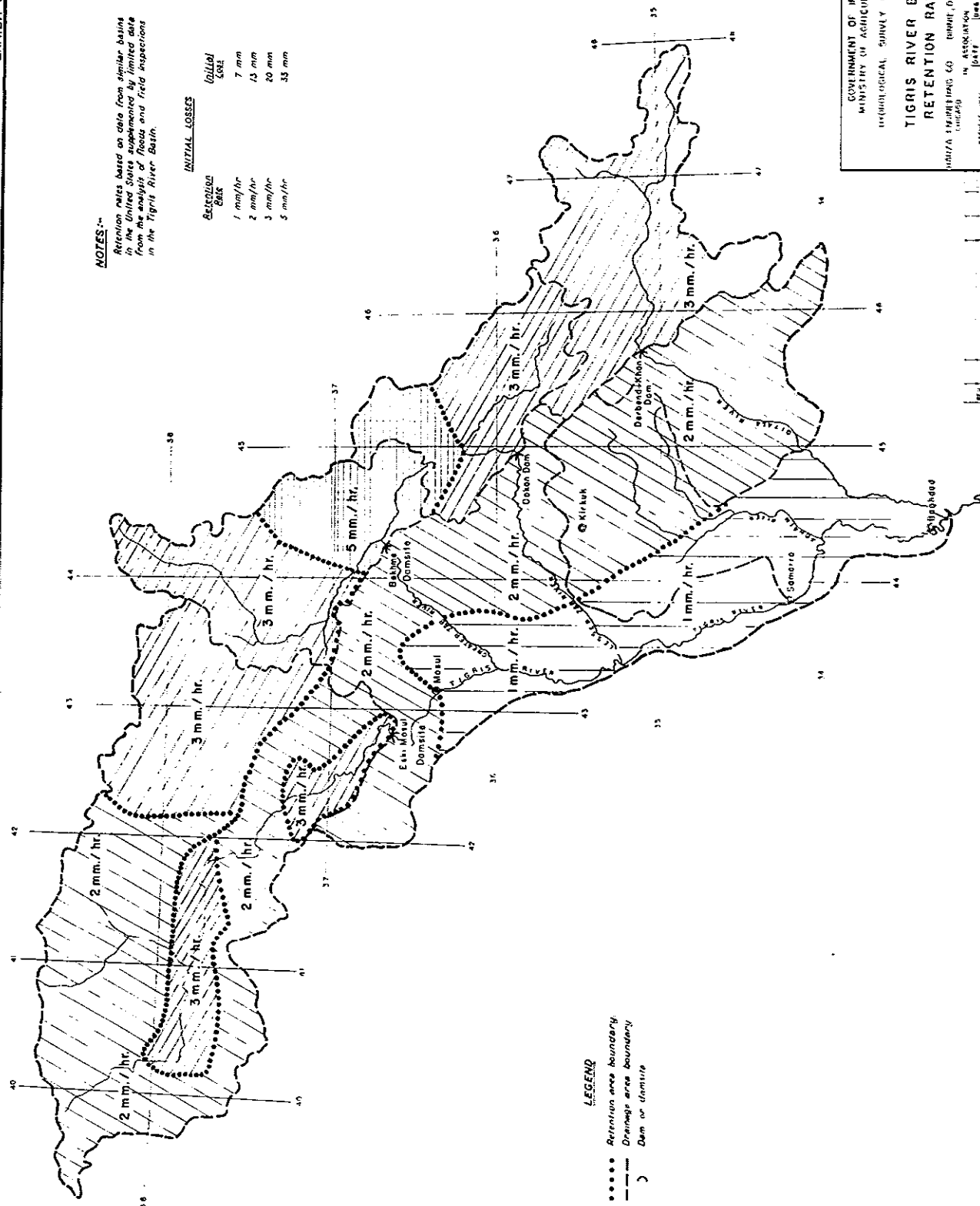
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NOTES:-

Retention rates based on data from similar basins in the United States supplemented by limited data from the analysis of floods and field inspections in the Tigris River Basin.

INITIAL LOSSES

Retention Rate	Initial Loss
1 mm/hr	7 mm
2 mm/hr	15 mm
3 mm/hr	20 mm
5 mm/hr	35 mm



LEGEND

- Retention area boundary
- Drainage area boundary
- x— Dam or damsite

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

**TIGRIS RIVER BASIN
RETENTION RATES**

MAH/TA ENGINEERING CO. ENGINEERING CONSULTANTS
IN ASSOCIATION
WITH
RAHMAN, MEYER & ASSOCIATES
INCORPORATED
CHICAGO, ILL.
DESIGNED BY: MEYER
CHECKED BY: MEYER
DATE: 10/27/57
PROJECT NO. 027-9

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(d) SAMPLE DERIVATION

Bekhme unit hydrograph
Drainage area = 16,600 Sq km.

(From a.)

Unit peak = 0.065 cumecs/Sq. km.
Unit peak = 1080 cumecs

(From b.)

Width at 75% peak = 25 hours
Width at 50% peak = 42 hours

(From c.)

Runoff distribution for 42 hours lag time

Day	Percent
1	5
2	28
3	28
4	17
5	12
6	6
7	4

NOTE:

$\log \text{ time} = C_1 (L/L_0)^{0.3}$

L = river channel length from station to upstream limit of drainage area in kilometers

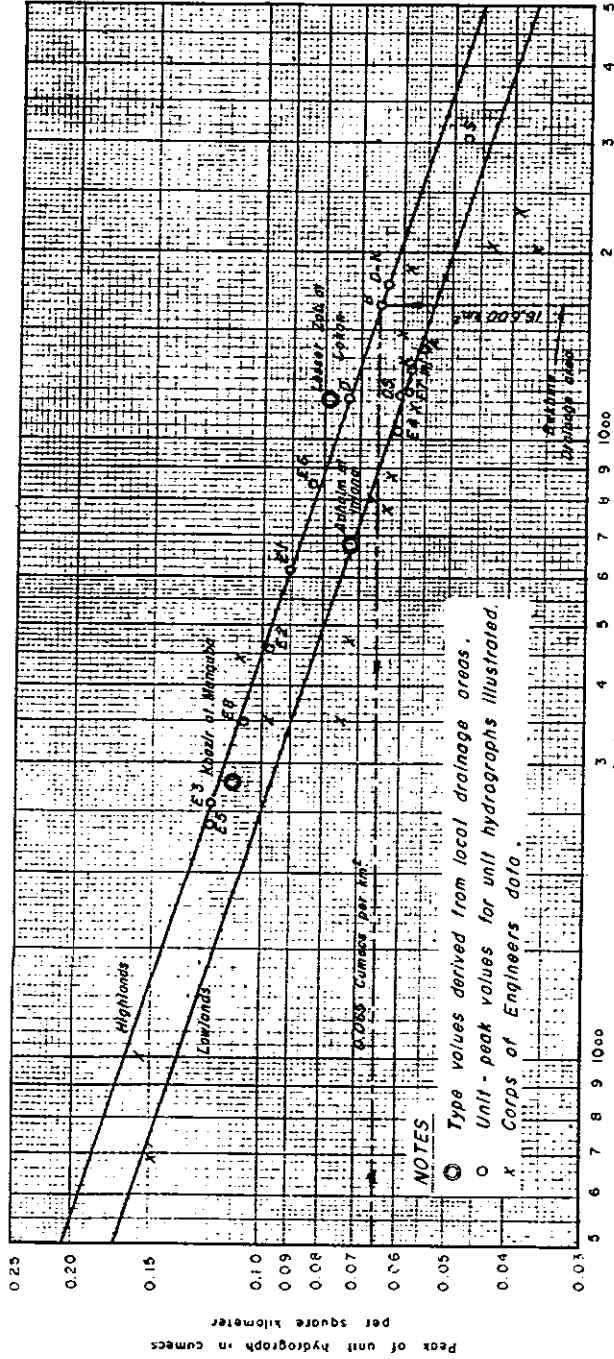
L_0 = river channel length from station to center of gravity of drainage area.

C_1 = constant (1.8 for highlands and 1.7 for lowlands)

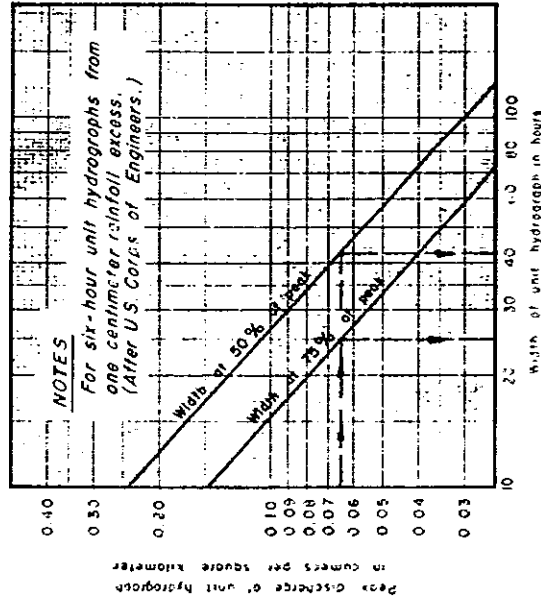
GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

SYNTHETIC UNIT HYDROGRAPH
RELATIONS

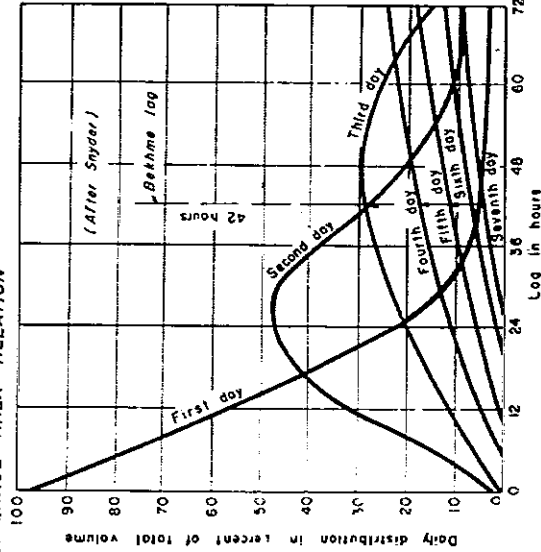
UNIVERSITY OF BAGHDAD
FACULTY OF ENGINEERING
HYDROLOGICAL ENGINEERING
1955
15 MAR 58
627-16



(a) SIX-HOUR UNIT HYDROGRAPH PEAK- DRAINAGE AREA RELATION

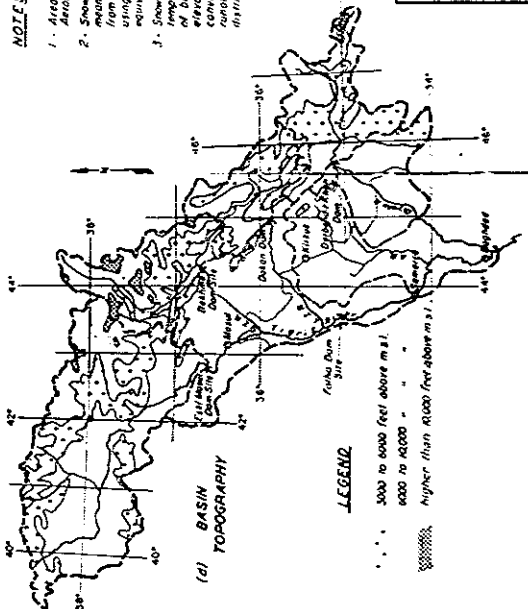
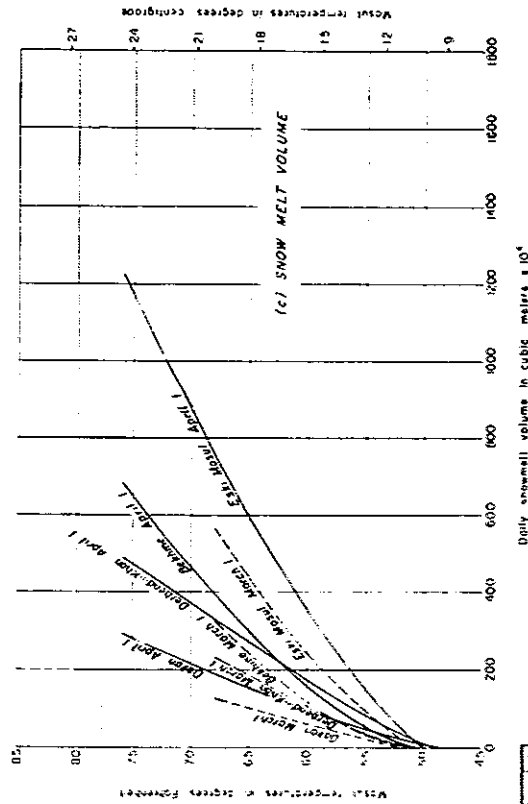
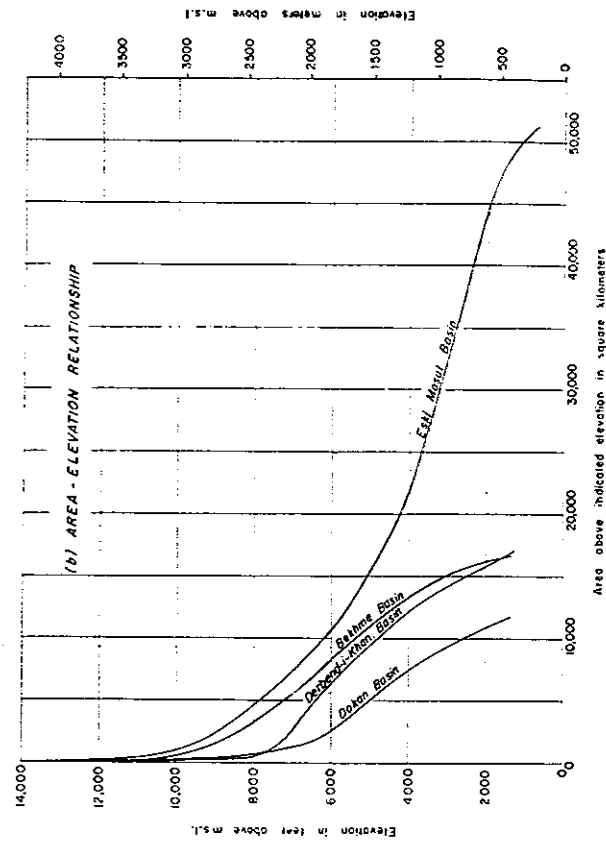
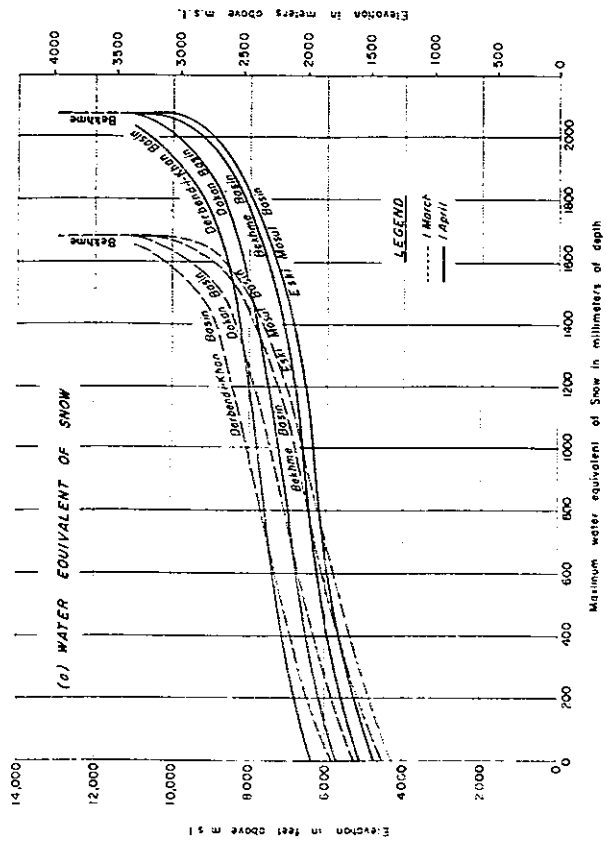


(b) UNIT HYDROGRAPH WIDTHS



(c) UNIT HYDROGRAPH VOLUME DISTRIBUTION

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NOTES:

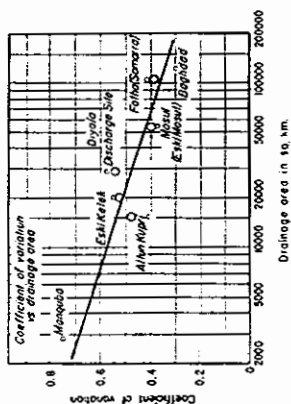
1. Area-elevation curves and topographic data from "World Anatomical Charts", Scale 1:1,000,000.
2. Snow water equivalent curves computed from observed mean winter precipitation for basin, using correlation from California (U.S.) snow survey, and maximum water equivalent from California snow survey.
3. Snow melt curves based on relation between basal temperature and melt factor of 1 mm per degree-day at basin melting temperature, assuming minimum snow at basin melting temperature, and maximum snow at basin melting temperature. Snowmelt curves were converted to melt in one day rather than a rate of melt. Runoff from one day's melt assumed to be distributed over 20 days.

GOVERNMENT OF IRAQ
 MINISTRY OF AGRICULTURE
 HYDROLOGICAL SURVEY OF IRAQ

SNOW DATA, AREA-ELEVATION
 CURVES, AND BASIN TOPOGRAPHY

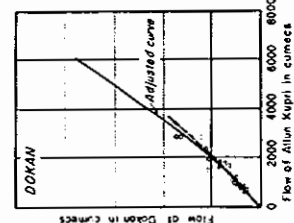
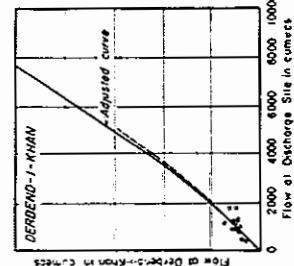
IRRAWADDI TRIBUTARIES: CD TUNNIC, DEAGNI B. GOMUKI
 LITH: 100 M. ASSOCIATION
 MAP: 100 M. ASSOCIATION
 DATE: 17 July 1964
 SHEET NO: 023-3

BEST AVAILABLE COPY

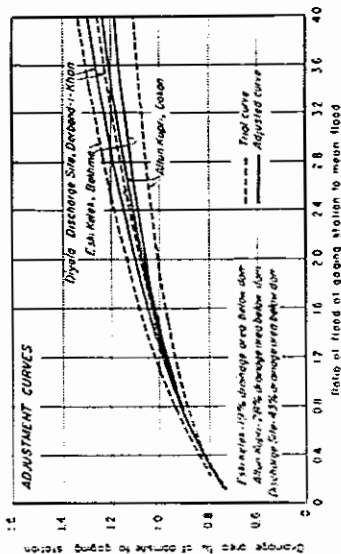


LEGEND
 ○ Values of cv and mean flood computations for gaging station record
 ● Partial adjustment to agree with basin curve, as used in frequency computations

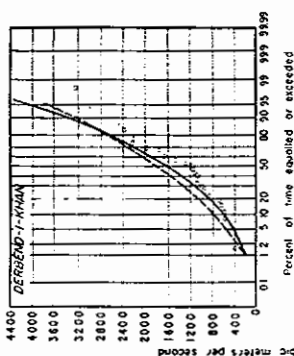
• •



NOTE. Adjustment curves represent changes to male flow contributions between damilles and gaging stations consistent with contributing areas below damilles.



(10) DAM SITE TO GAGING STATION CORRELATIONS



The graph plots Peak annual flow (ESRI MOSAT) on the Y-axis against Percent of time equalled or exceeded on the X-axis. The Y-axis ranges from 0 to 10,000 in increments of 1,000. The X-axis ranges from 0 to 100 in increments of 5. A smooth curve is drawn through the data points, showing a decreasing trend. The data points are approximately as follows:

Percent of time equalled or exceeded	Peak annual flow (ESRI MOSAT)
0	10,000
10	8,500
20	7,500
30	6,800
40	6,200
50	5,800
60	5,200
70	4,800
80	4,200
90	3,500
100	1,000

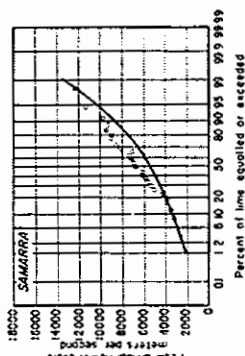
Figure 1 is a line graph with the following data points estimated from the plot:

Percent of Time Applied or Exceeded	BEHME (Computed with ESK Method)	BEHME (Computed with ESK Method and Cx)
0.1	~9500	~8500
1.2	~8500	~7500
10	~6500	~5500
20	~5500	~4500
50	~3500	~2500
80	~2000	~1500
95.95	~1000	~800

UNCLASSIFIED

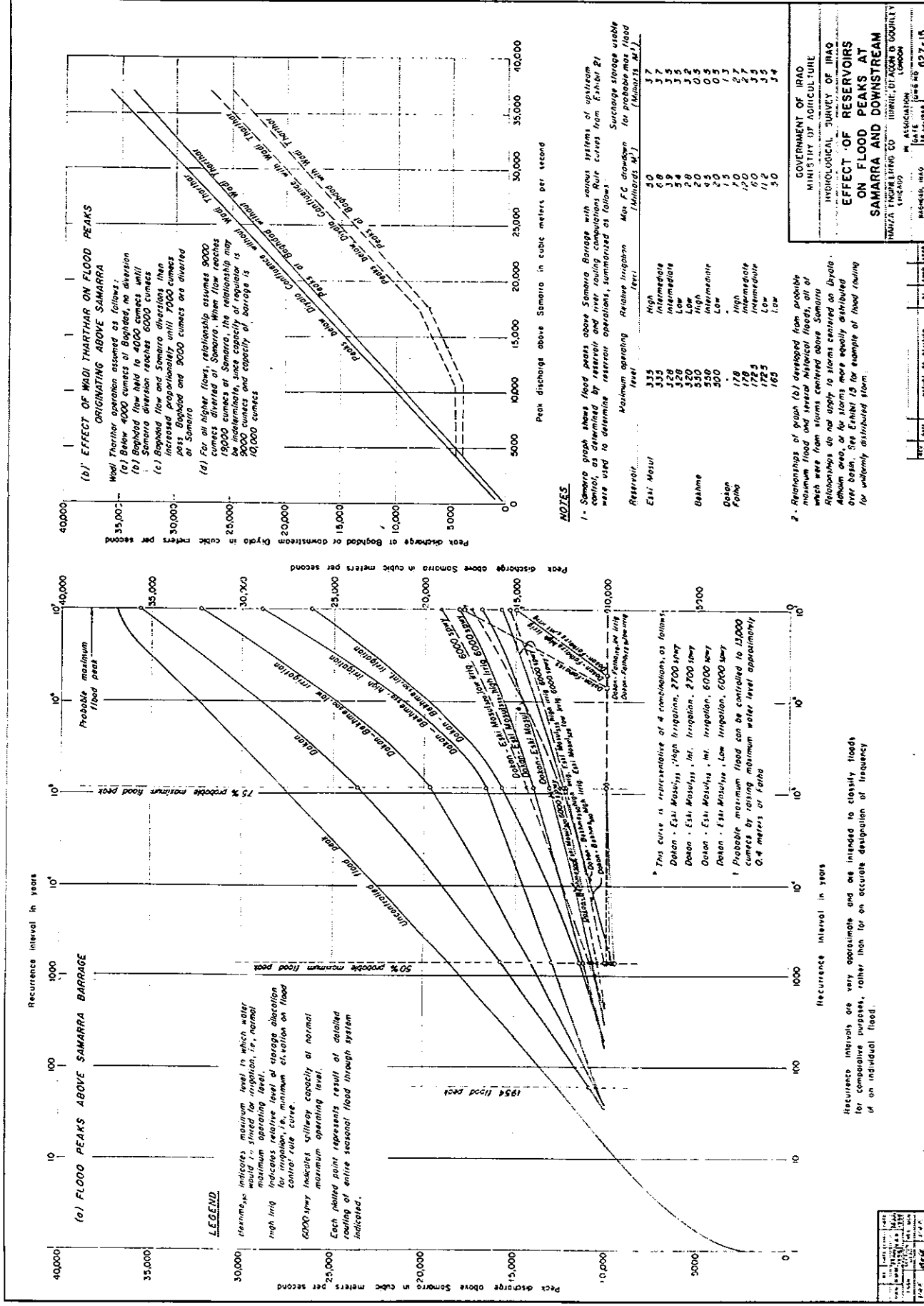
Historic flood at gaging station.

--- Frequency curve for gauging station computed on basis of weighted average C_p for dams and values of C_p and mean flood from Fig. 10 (a)
 ----- Applied curve for dams on basis of correlation between damsite and gauging station (in Chin Matsui and Samaga curve is same as -----)



(c) FREQUENCY CURVES

214-



(a) FLOOD PEAKS ABOVE SAMARRA BARRAGE

LEGEND

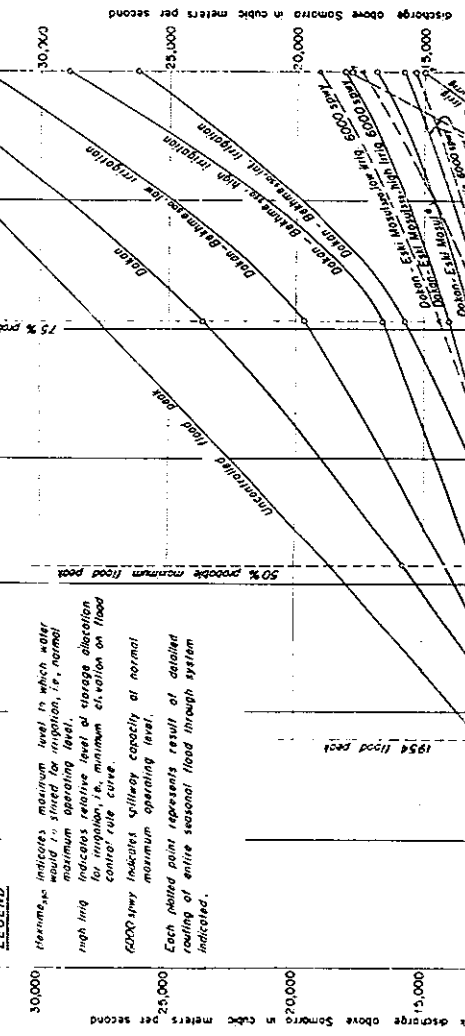
- Indicates maximum level in which water would be stored for irrigation, i.e., normal high flow
- Indicates storage capacity of storage allocation for irrigation, i.e., minimum elevation on flood control rule curve
- 6000 cusec indicates spillway capacity at normal maximum operating level
- Each plotted point represents result of detailed routing of entire seasonal flood through system indicated

Recurrence intervals are very approximate and are intended to classify floods for comparative purposes, rather than for an accurate designation of frequency of an individual flood.

(b) EFFECT OF WADI THARTHAR ON FLOOD PEAKS ORIGINATING ABOVE SAMARRA

- Wadi Tharthar operation assumed as follows:
 - (a) Below 4000 cusecs at Baghdad, no diversion
 - (b) Between 4000 cusecs and 10000 cusecs at Baghdad, flow held to 4000 cusecs until Samarra reaches 6000 cusecs
 - (c) Between 10000 cusecs and 19000 cusecs at Baghdad, flow and Samarra are diverted then increased proportionately until 19000 cusecs pass Baghdad and 9000 cusecs are diverted at Samarra
 - (d) For all higher flows, relationship assumes 9000 cusecs diverted at Samarra and 10000 cusecs be maintained, since capacity of barrage is 9000 cusecs and capacity of barrage is 10,000 cusecs

Peak discharge above Samarra in cubic meters per second



NOTES

1. Samarra graph shows flood peaks above Samarra Barrage with various systems of upstream control, as determined by reservoir and river routing computations. Rule curves from Exhibit 21 were used to determine reservoir operations, summarized as follows:

Reservoir	Level	Maximum operating level	Relative irrigation	Max. F.C. diversion	Surcharge storage usable for probable flood
Elisi Mosul	High	335	High	100	3.7
	Intermediate	330	Intermediate	90	3.7
	Low	325	Low	80	3.5
Baghdad	High	320	High	20	0.5
	Intermediate	315	Intermediate	15	0.5
	Low	310	Low	10	0.5
Qadisiyah	High	178	High	70	2.7
	Intermediate	175	Intermediate	60	2.7
	Low	172	Low	50	2.5
Fatha	High	165	High	30	2.4

2. Specifications of graph (b) developed from probable maximum flood and various historical floods, all of which were from storms centered above Samarra. Relationships do not apply to storms centered on Baghdad, Adhamiya, or for storms more evenly distributed over basin. See Exhibit 13 for example of flood routing for uniformly distributed storm.

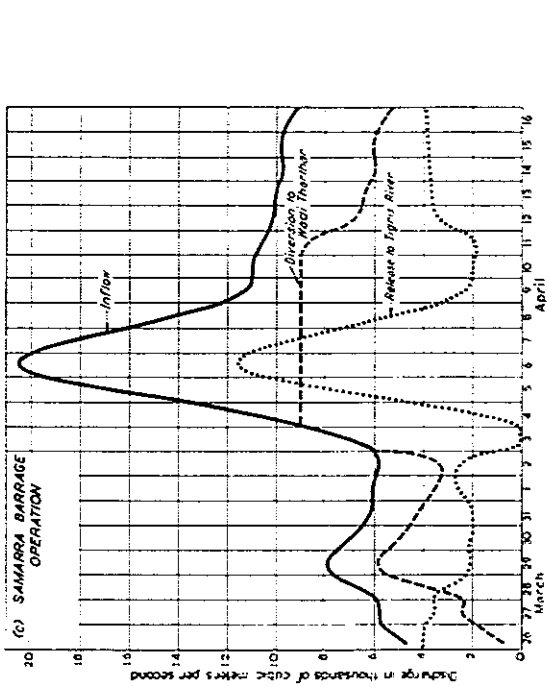
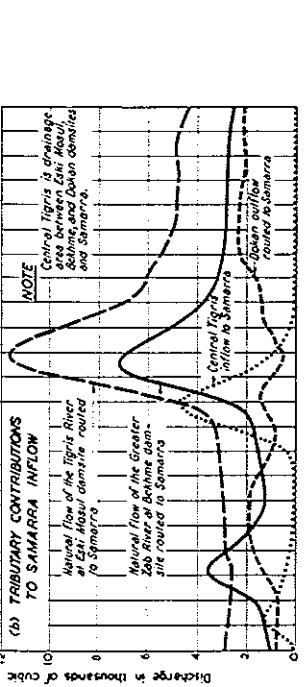
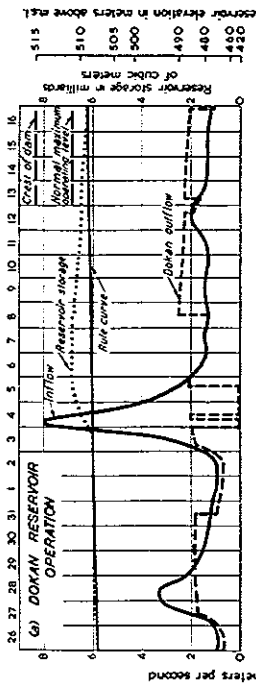
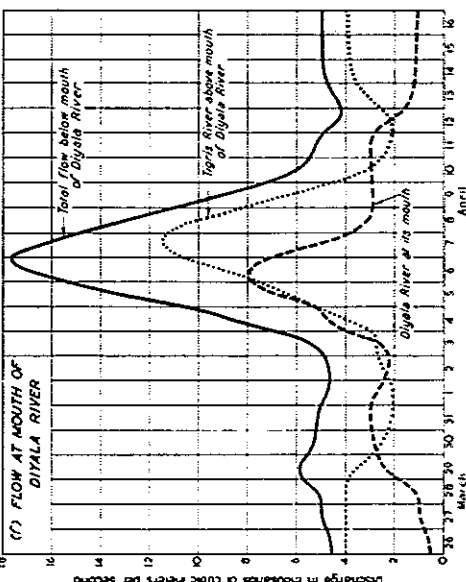
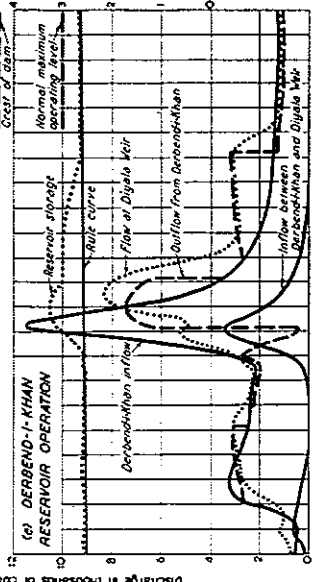
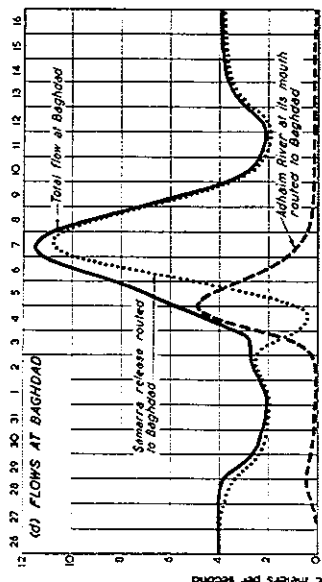
GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ
EFFECT OF RESERVOIRS ON FLOOD PEAKS AT SAMARRA AND DOWNSTREAM
H.M.A. ENGINEERING CO. (INCORPORATED IN U.K.)
Date: 15/10/1958
Sheet No. 027-15

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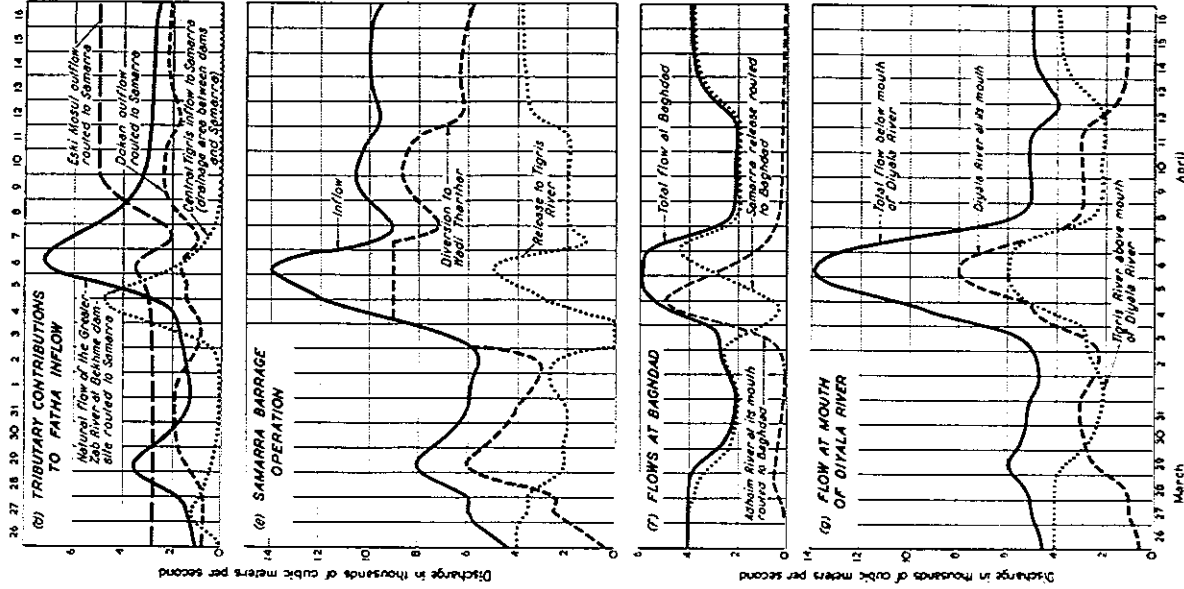
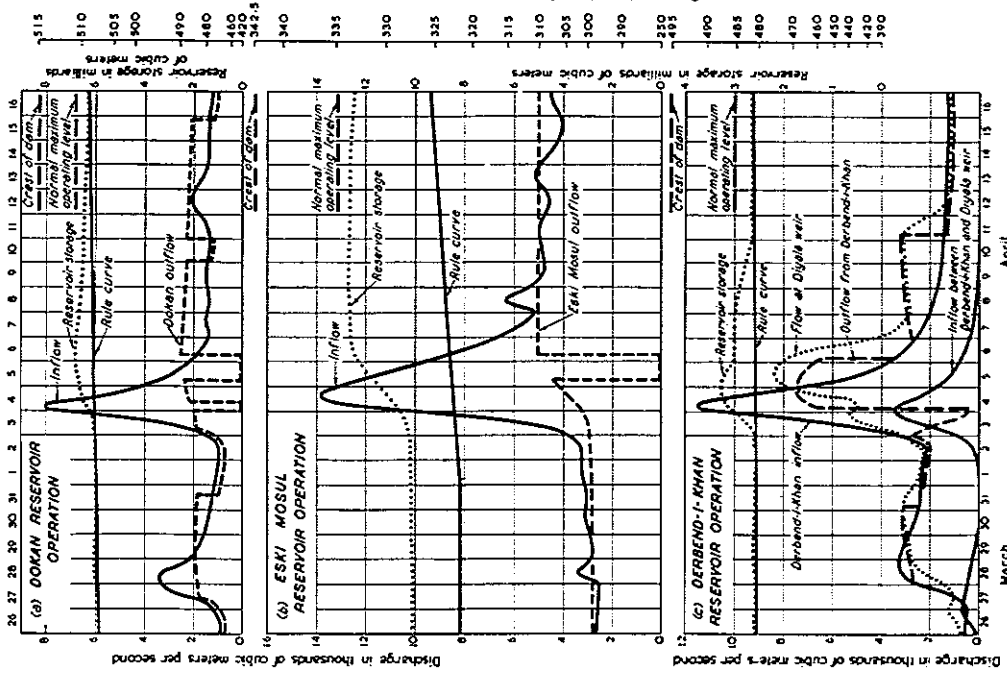
NOTES:

1. This operation is for the existing system. It is based on the assumption that the diversion facilities, and Derbend-Khan Reservoir.
2. Operation is for a flood having an unregulated peak flow at the mouth of the Diyala River of 43,000 cusecs. The peak flow is 90% of the probable maximum flood.
3. Sub-basin inflows are assumed to be based on probable maximum flood peaks. Sub-basin probable maximum peaks must be multiplied by 0.65 to give 80% probable maximum peak below mouth of Diyala.
4. Rule curves and discharge capabilities shown on Exhibit 21 are used.
5. Dukan Reservoir is operated to limit Samarra inflow to 4000 cusecs when reservoir is in normal operating level. The reservoir is operated to limit Samarra inflow to 4000 cusecs when in upper half of joint use allocation. Reservoir discharges inflows when at normal operating level. Water in storage in joint use allocation is released in a similar manner.
6. Samarra Barrage is operated to limit Baghdad flows to 4000 cusecs, or to limit flows below the mouth of the Diyala River to 5000 cusecs whenever possible. Capacity of diversion assumed to be 8000 cusecs.
7. Derbend-Khan Reservoir is operated to limit flows at Diyala Weir to 3000 cusecs while reservoir is below normal maximum operating level.

GOVERNMENT OF IRAQ	
MINISTRY OF AGRICULTURE	
HYDROLOGICAL SURVEY OF IRAQ	
FLOOD CONTROL OPERATION	
EXISTING SYSTEM	
YANZA ENGINEERING CO.	ENGINEERS IN CHARGE
CHICAGO	ASSOCIATION
DATE	17 MAY 1948
PROJECT NO.	612-14



BY	DATE	REVISION
1	17 MAY 1948	1

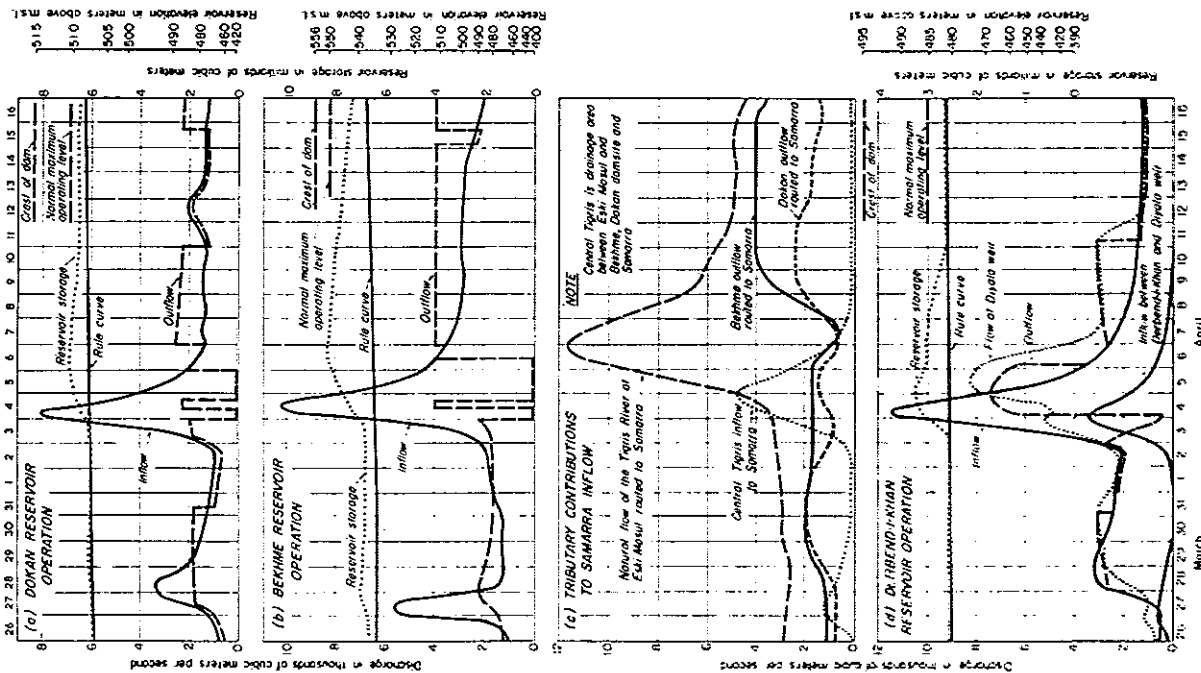


NOTES:

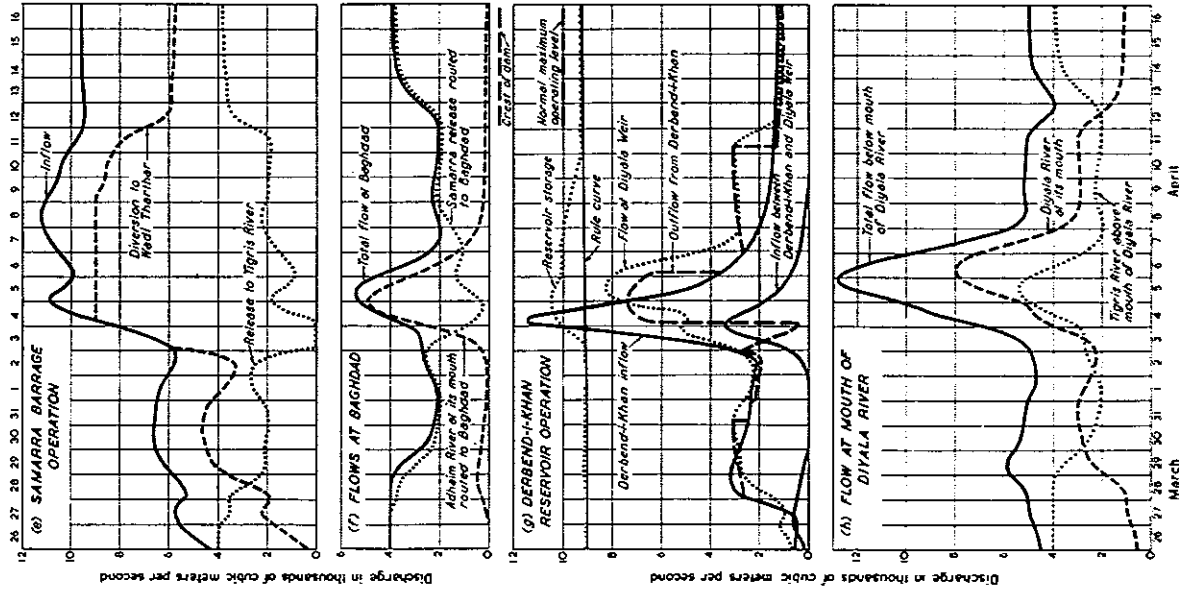
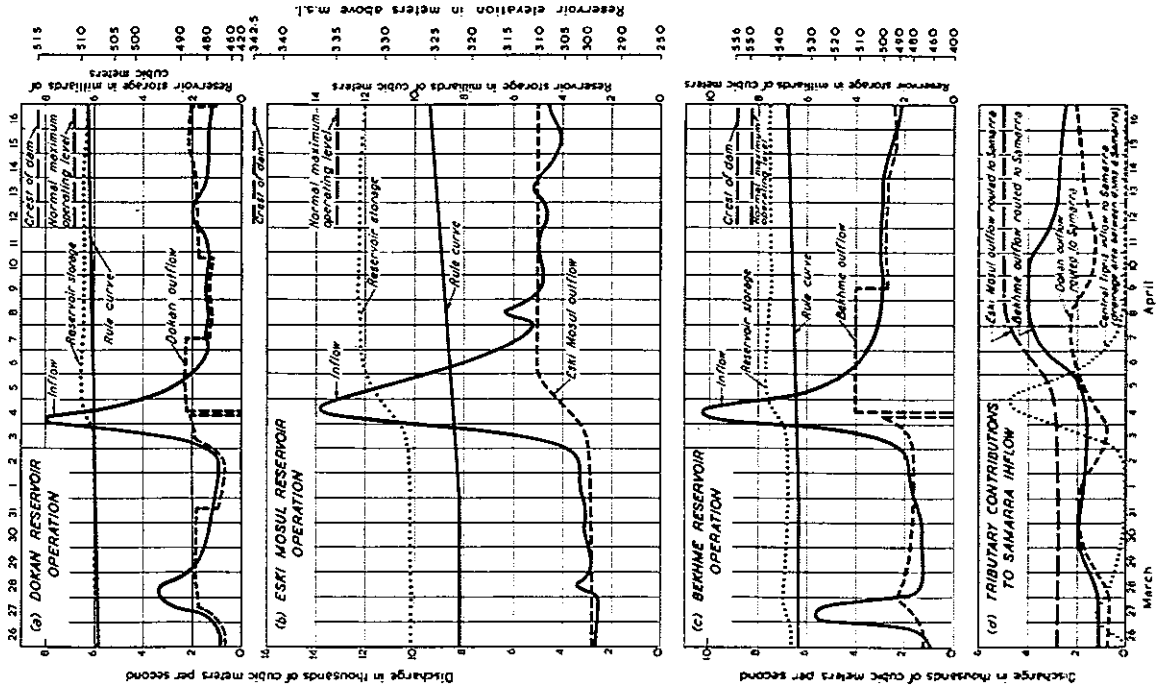
- 1 - This operation is for a system consisting of Dukan Reservoir, High Eski Mosul Reservoir, the existing Samarra diversion facilities, and Derbend-i-Khan Reservoir.
- 2 - Operation is for a flood having an unregulated peak flow below the mouth of the Dukan River of 20,700 cubic meters per second (80% of the probable maximum flood).
- 3 - Sub-basin inflows are assumed to be proportional to the probable maximum flood. The probable flood peak, Sub-basin probable maximum peaks must be multiplied by 0.43 to give 90% probable maximum peak below mouth of Diyala.
- 4 - Rule curves and discharge capabilities shown on Exhibit 21 are used.
- 5 - Dukan and Eski Mosul Reservoirs are operated to limit Samarra inflow to 10,000 cumecks when the mouth of the Diyala River to 5000 cumecks whenever possible. Capacity of diversion use allocation, the operation is assumed to limit Samarra inflow to 10,000 cumecks when in the upper half of joint use allocation. Reservoirs discharge inflows when at normal maximum operating level. Water in storage in joint use allocation is released in a similar manner.
- 6 - Samarra Barrage is operated to limit Baghdad flows to 4000 cumecks, or to limit flows below the mouth of the Diyala River to 5000 cumecks whenever possible. Capacity of diversion assumed to be 1000 cumecks.
- 7 - Derbend-i-Khan Reservoir is operated to limit flows at Diyala Weir to 5000 cumecks while reservoir is below normal maximum operating level.

GOVERNMENT OF IRAQ MINISTRY OF AGRICULTURE	
HYDROLOGICAL SURVEY OF IRAQ	
FLOOD CONTROL OPERATION EXISTING SYSTEM PLUS HIGH ESKI MOSUL	
UNIVERSITY OF CHICAGO ENGINEERING CO. UNIV. OF CHICAGO CHICAGO	DATE 10-1-54 BY J. H. HARRIS
REVISION NO. 1	FIG. 12-12

NO. 1212	DATE 10-1-54	BY J. H. HARRIS
1212	10-1-54	J. H. HARRIS



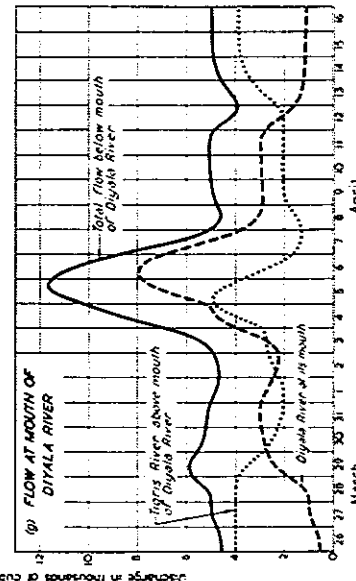
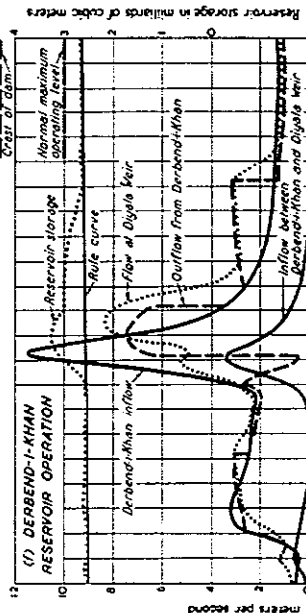
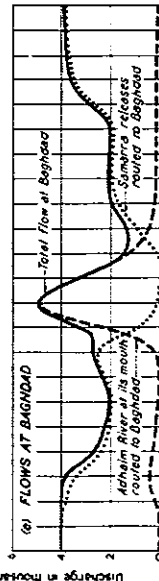
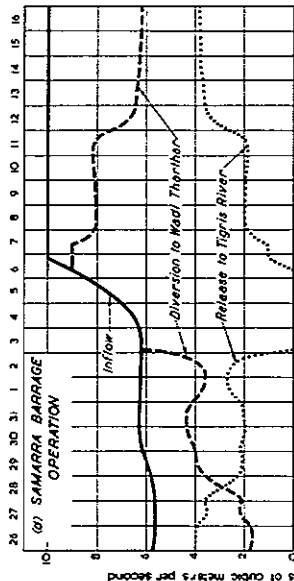
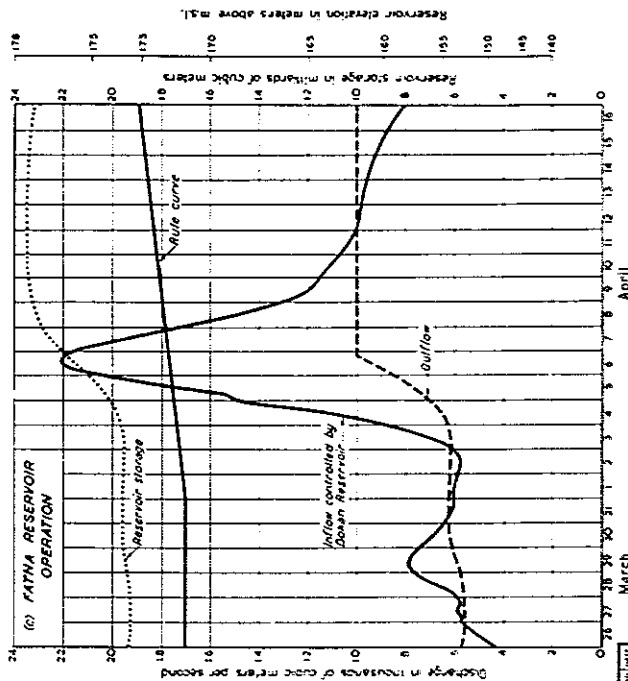
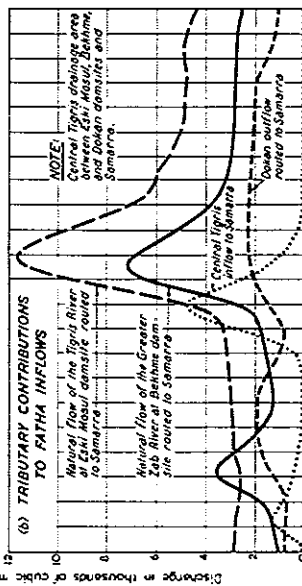
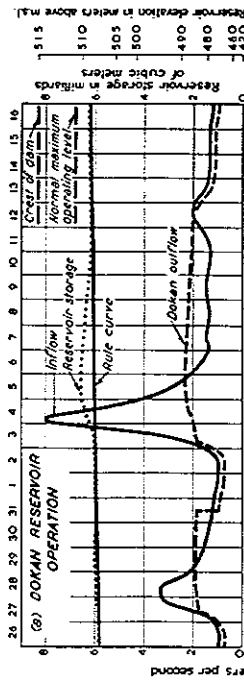
1. This operation is for a system consisting of Datto Reservoir, High Bhatana Reservoir (El 540), the existing Samara diversion facilities, and Dardang-Khon Reservoir.
2. Operation is for a flood having an unregulated peak flow of 10,000 cumecs. Datto River of 267,000 cubic meters per second (100% of the probable maximum flood).
3. Sub - basin inflows are assumed to be proportional to be individual sub-basins probable maximum peak peak. Sub-basin probable maximum peak must be multiplied by 0.425 to give 100% probable maximum below mouth of Datto.
4. Rule curves and discharge capabilities shown on Exhibit 21 are used.
5. Datto and Bhatana reservoirs are operated to limit Samara inflow to 10,000 cumecs when reservoir levels are in the lower half of the joint use allocation. The reservoirs are operated to limit Samara inflow to 15,000 cumecs when the reservoirs are in the upper half of the joint use allocation. The reservoirs discharge inflows when at normal operating level.
6. Samara Storage is operated to limit Dardang-Khon inflow to 10,000 cumecs. Datto River inflow below the mouth of the Datto to 5000 cumecs is assumed possible. Capacity of diversion assumed to be 9000 cumecs
7. Dardang-Khon Reservoir is operated to limit flow at Datto River to 10000 cumecs while reservoir is below normal operating level.



NOTES:

- 1 - This operation is for a system consisting of Dohuk Reservoir, High Eski Mosul Reservoir, High Bekhme Reservoir, the existing Samarra diversion facilities, and Derbend-i-Khan Reservoir.
- 2 - Operation is for a flood having an unregulated peak flow below the mouth of the Diyala River of 28,100 cubic meters per second (80% of the probable maximum flood).
- 3 - Sub-basin inflows are assumed to be proportional to the individual sub-basins probable maximum flood peak. Sub-basin probable maximum peaks must be multiplied by 0.455 to give 80% probable maximum peak below mouth of Diyala.
- 4 - Rule curves and discharge capabilities shown on Exhibit 21 are used.
- 5 - Dohuk, Bekhme and Eski Mosul Reservoirs are operated to limit Samarra inflow to 8000 cumecs when the reservoirs are in the lower half of joint use allocation. The reservoirs are operated to limit Samarra inflow to 14,000 cumecs when in the upper half of joint use allocation. Reservoir discharge inflows when at normal operating level are stored in joint use allocation and released in a similar manner.
- 6 - Samarra Barrage is operated to limit Baghdad flows to 4000 cumecs, or to limit flows below the mouth of the Diyala River to 2000 cumecs when at normal operating level. Outflow of operation assumed to be 9000 cumecs.
- 7 - Derbend-i-Khan Reservoir is operated to limit flows at Diyala Weir to 5000 cumecs while operation is below normal maximum operating level.

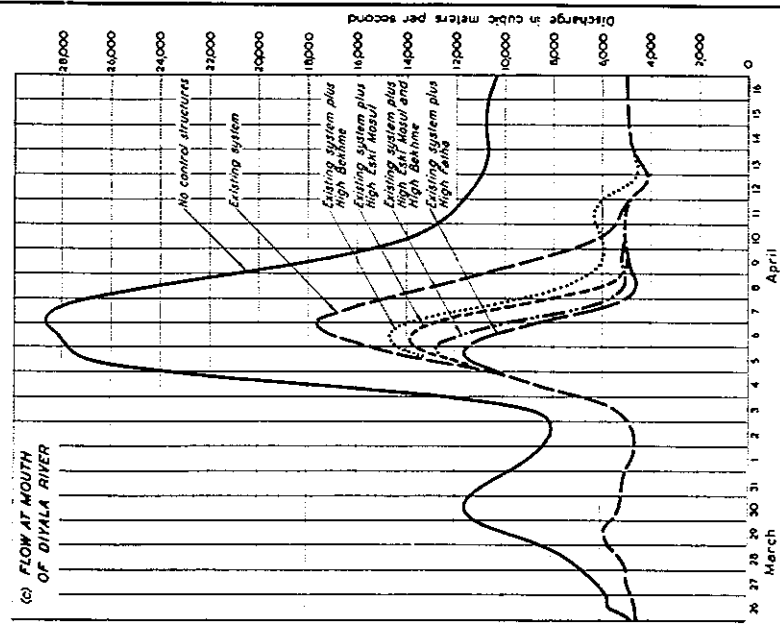
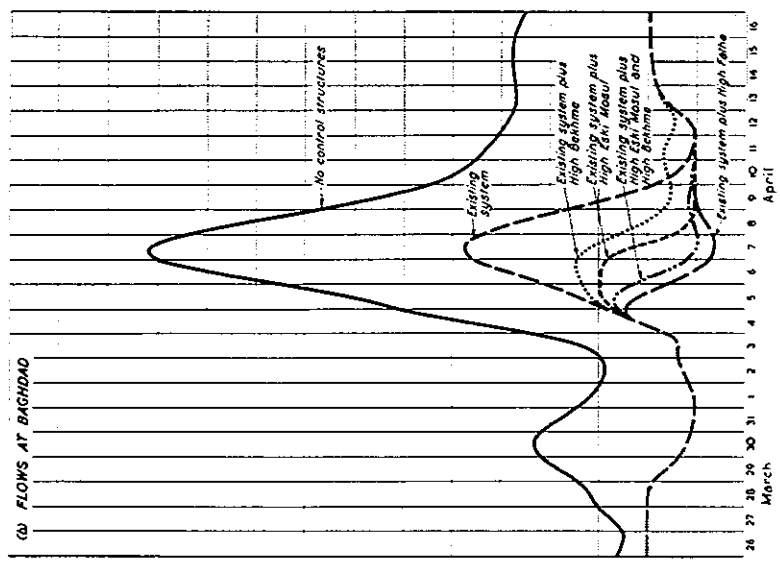
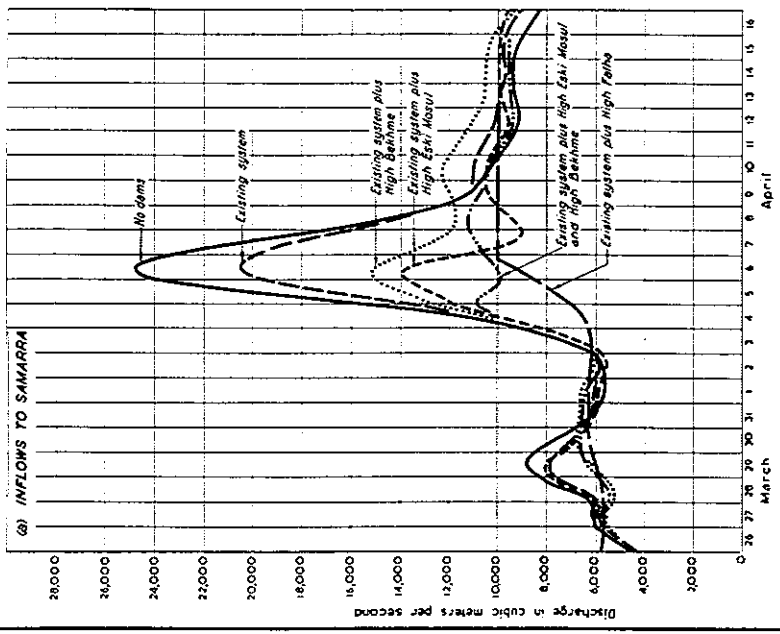
GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ
FLOOD CONTROL OPERATION
EXISTING SYSTEM PLUS
HIGH ESKI MOSUL & HIGH BEKHME
TAMAZA ENGINEERING CO. TRINITE, DRYADEN & GUILLOT
CHICAGO
DATE: 10th MAY 1966
SHEET NO. 012-13



NOTES:

1. This operation is for a system consisting of Dokan Reservoir, High Fatha Reservoir, existing Fatha Reservoir facilities, and Derbend-i-Khan Reservoir.
2. Operation is for a flood having an unregulated peak flow below the mouth of the Diyala River of 10,000 cusecs, meters per second (100% of the probable maximum flood).
3. Sub-basin inflows are assumed to be proportional to the individual sub-basin's probable maximum flood peak. Sub-basin inflows are assumed to be routed by 0.45 to give 80% probable maximum peak below mouth of Diyala.
4. Rule curves and discharge capabilities shown on Exhibit E1 are used.
5. Dokan Reservoir is operated at discharge capability at all times when reservoir is above rule curve level. Fatha Reservoir is operated at discharge capability except in flood peaks above 10,000 cusecs when reservoir is below normal maximum operating level.
6. Samarra Barrage is operated to limit flood flow to 4000 cusecs, or to limit flow from the Tigris River to 5000 cusecs whenever possible. Capacity of diversion assumed to be 1000 cusecs.
7. Derbend-i-Khan Reservoir is operated to limit flood flow to 4000 cusecs, or to limit flow from the Tigris River to 5000 cusecs while reservoir is below normal maximum operating level.

GOVERNMENT OF IRAQ		MINISTRY OF AGRICULTURE	
HYDROLOGICAL SURVEY OF IRAQ		FLOOD CONTROL OPERATION	
EXISTING SYSTEM		PLUS HIGH FATHA	
NABAZA ENGINEERING CO. BUNNIE DRAGON IN CHARGE		CHICAGO	
IN ASSOCIATION WITH		U.S. ARMY CORPS OF ENGINEERS	
REPORT NO. 612-11		DATE 15 MAY 1944	



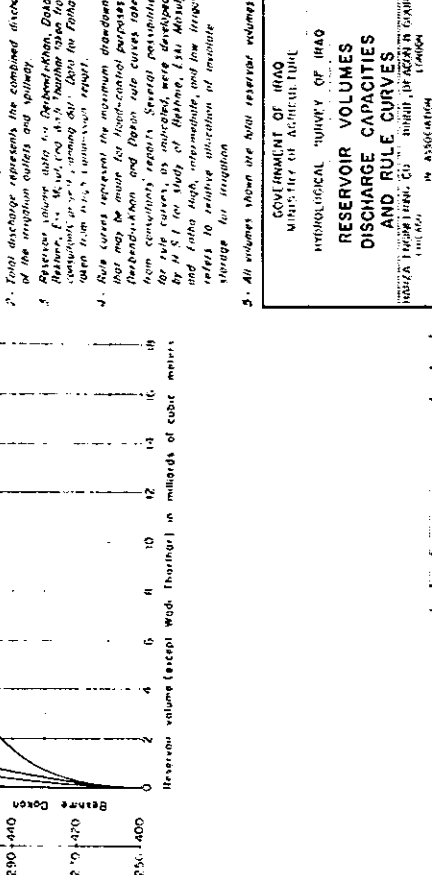
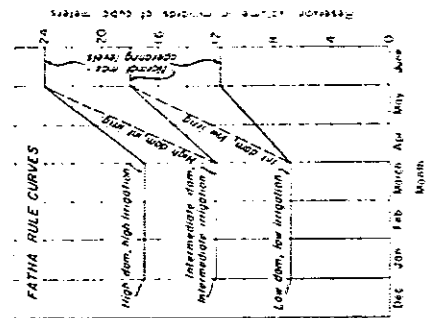
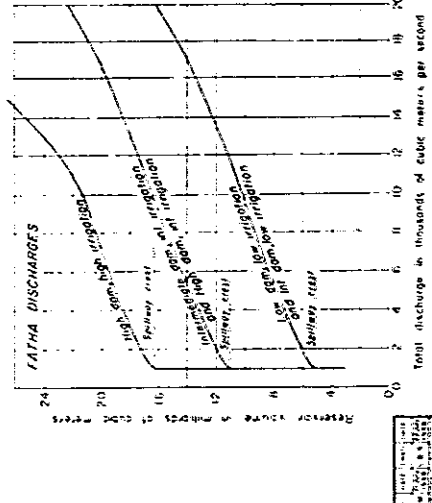
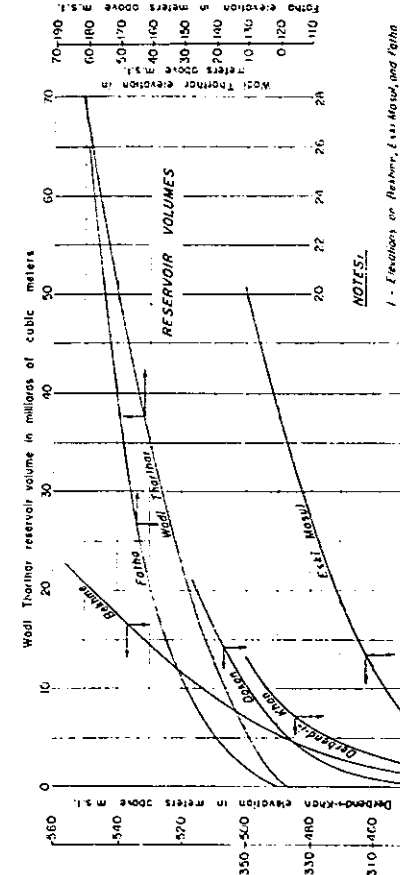
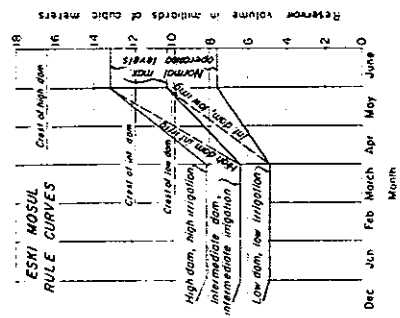
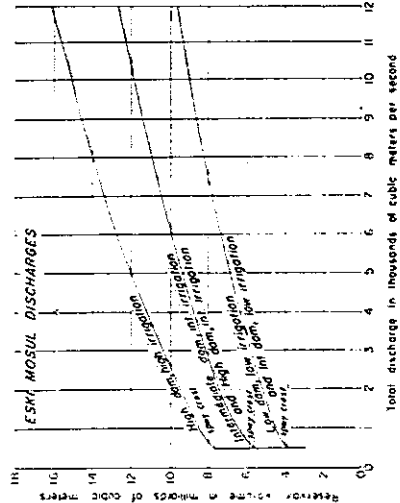
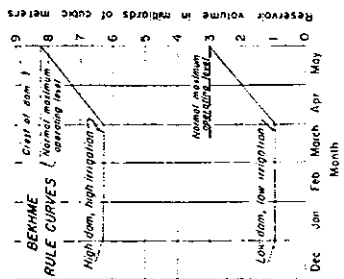
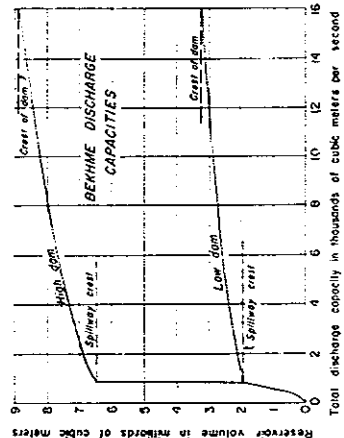
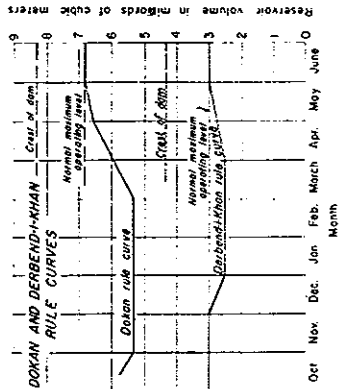
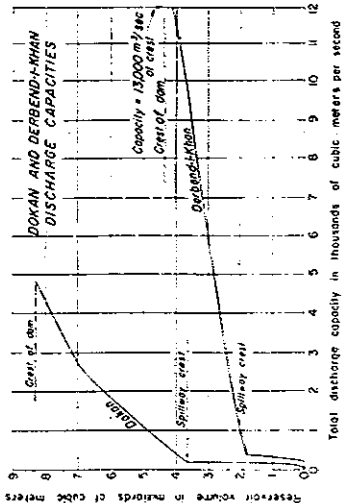
- NOTES:**
1. Operation is for a flood having an unregulated peak flow below the mouth of the Diyala River of 28,000 cubic meters per second (80% of the probable maximum flood).
 2. Sub-basin inflows are assumed to be proportional to the individual sub-basin probable maximum flood peak. Sub-basin probable maximum peak must be multiplied by 0.455 to give 80% probable maximum peak below mouth of Diyala.
 3. For details of individual system operations, see Exhibits 15 through 19.

GOVERNMENT OF IRAQ
 MINISTRY OF AGRICULTURE
 HYDROLOGICAL SURVEY OF IRAQ
 REGULATED FLOOD PEAKS
 AT SAMARRA
 AND DOWNSTREAM

INITIAL REVIEWED BY: []
 APPROVED BY: []
 DATE: []
 SCALE: []
 SHEET NO.: []
 TOTAL SHEETS: []

DATE	TIME	WATER	WIND	TEMP.	WAVE	SEA	WAVE	SEA	WAVE	SEA
26	12	10	10	10	10	10	10	10	10	10
27	12	10	10	10	10	10	10	10	10	10
28	12	10	10	10	10	10	10	10	10	10
29	12	10	10	10	10	10	10	10	10	10
30	12	10	10	10	10	10	10	10	10	10
31	12	10	10	10	10	10	10	10	10	10
1	12	10	10	10	10	10	10	10	10	10
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3	12	10	10	10	10	10	10	10	10	10
4	12	10	10	10	10	10	10	10	10	10
5	12	10	10	10	10	10	10	10	10	10
6	12	10	10	10	10	10	10	10	10	10
7	12	10	10	10	10	10	10	10	10	10
8	12	10	10	10	10	10	10	10	10	10
9	12	10	10	10	10	10	10	10	10	10
10	12	10	10	10	10	10	10	10	10	10
11	12	10	10	10	10	10	10	10	10	10
12	12	10	10	10	10	10	10	10	10	10
13	12	10	10	10	10	10	10	10	10	10
14	12	10	10	10	10	10	10	10	10	10
15	12	10	10	10	10	10	10	10	10	10
16	12	10	10	10	10	10	10	10	10	10

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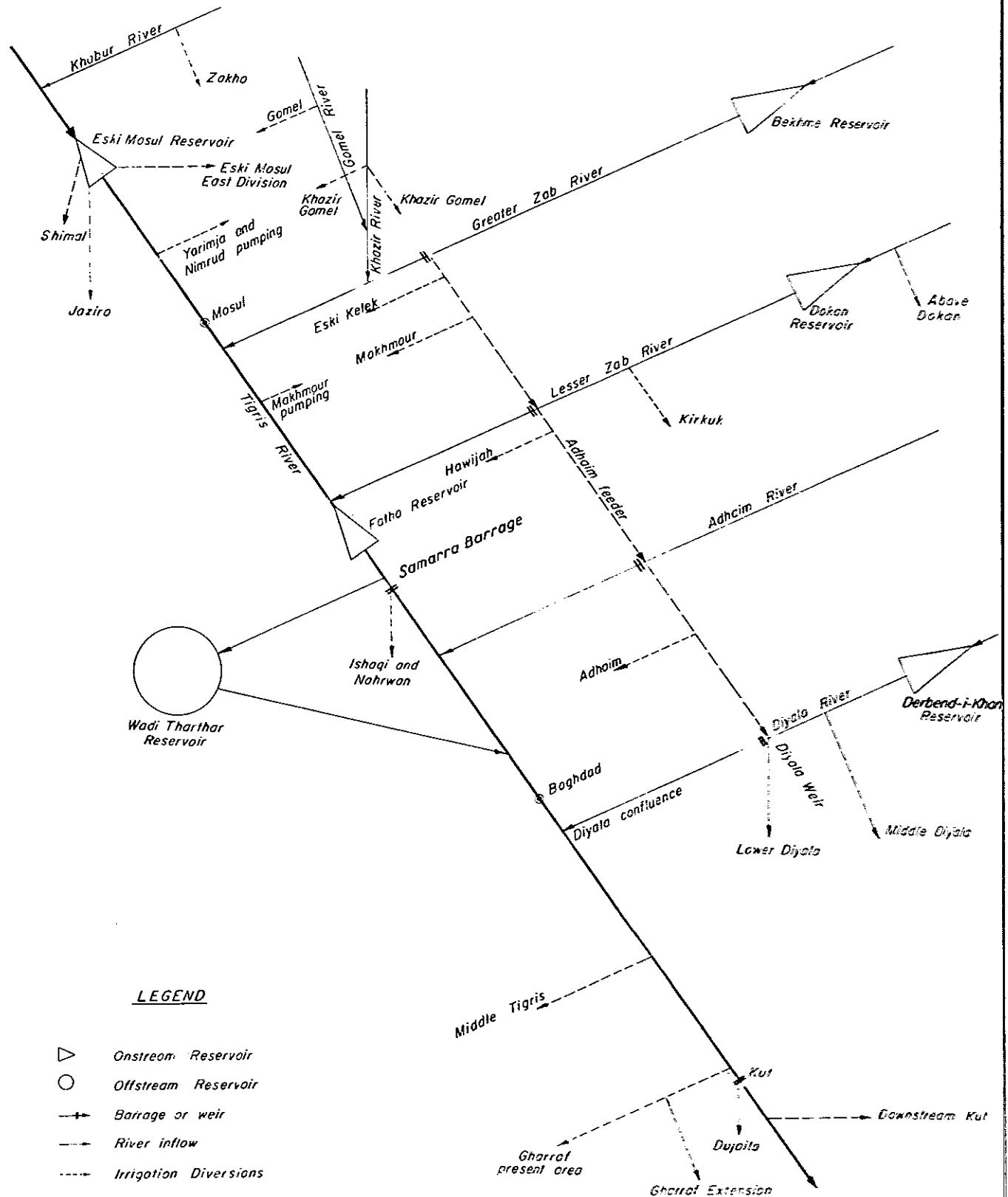


NOTES:

1. Elevation of Reservoir, Eski Mosul, and Fatha discharge curves are the elevations of normal maximum operating level.
2. Total discharge represents the combined discharge of the irrigation outlets and spillway.
3. Reservoir volume data for Derbend-Khan, Daman, and Fatha are based on the assumption that the reservoir is a rectangular prism with a base area of 100,000 sq. m. and a height of 100 m. The Fatha data are from the Fatha Survey Report.
4. Rule curves represent the maximum discharges that may be made for long-term storage (Derbend-Khan and Daman rule curves) and from conventional storage (Fatha rule curves). For rule curves, as indicated, were developed by U.S. for study of Fatha, Eski Mosul, and Fatha high, intermediate and low irrigation refers to relative allocation of available storage for irrigation.
5. All volumes shown are total reservoir volumes.

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ
**RESERVOIR VOLUMES
DISCHARGE CAPACITIES
AND RULE CURVES**
IRACIA 1960 (1960) 01
IN ASSOCIATION
WITH THE
BAGHDAD, IRAQ
027-17

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LEGEND

- ▷ Onstream Reservoir
- Offstream Reservoir
- +— Barrage or weir
- River inflow
- - - Irrigation Diversions

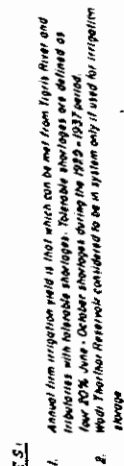
NOTE:

Har es Saniyah Reservoir added as offstream reservoir below Kut in some studies.

BY	DATE	CHKD	DATE
DAN	R.M.V.	1955	1955
ENGR	SEC. HEAD	RES. MGR	
ARR	R.A.R.	333	

REV. NO.	DATE	NOTE	BY	CHKD	DATE
1	JUNE 1959	Note			
		NATURE OF REVISION			

GOVERNMENT OF IRAQ	
MINISTRY OF AGRICULTURE	
HYDROLOGICAL SURVEY OF IRAQ	
SCHEMATIC DIAGRAM OF TIGRIS RIVER IRRIGATION SYSTEM	
HARZA ENGINEERING CO. CHICAGO	INNIS, DEACON & GOURLEY LONDON
IN ASSOCIATION	
BAGHDAD, IRAQ	DATE 22 JULY 1958
OWG NO.	680 - 5



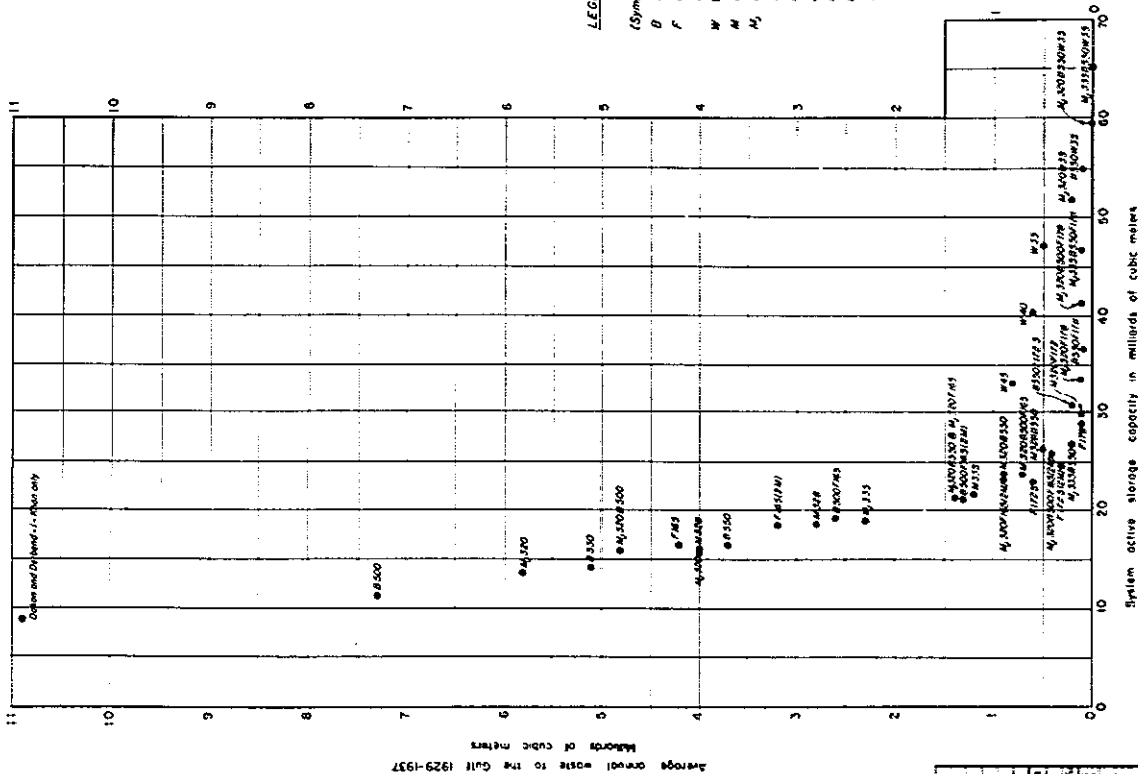
1 F G F N D:

- Symbols indicate addition to Corbett - 1. (thin = Odon system)
 a Baining Reservoir
 p Famine Reservoir (dam) and storage unless followed by P (multiplying Phillips dam storage)
 r Famine Reservoir (dam) and storage unless followed by P (multiplying Phillips dam storage)
 w Wolf Trout Reservoir
 x East about project irrigation without Jostin Project
 y East about project irrigation with Jostin Project
 Subscript figures for M, and P indicate the elevation for irrigation storage in meters above O.T.S. datum
 Subscript figures for W indicate level for irrigation outlet, in meters above O.T.S. datum
 Subscript figures for M, and P indicate the elevation for irrigation storage in meters above O.T.S. datum

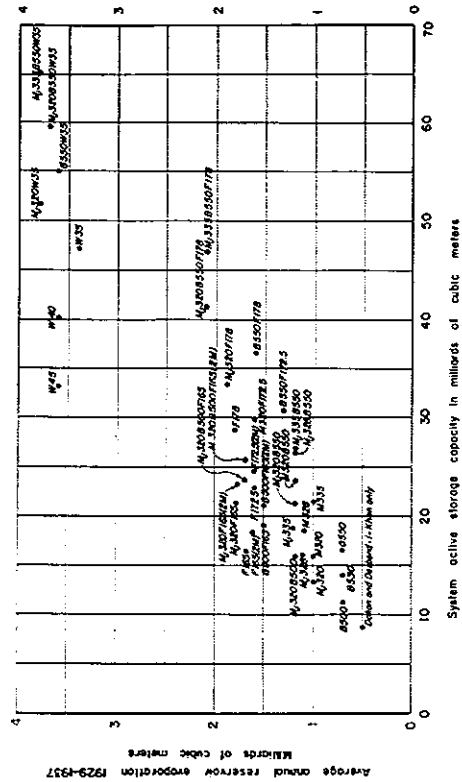
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(A)
WASTE TO BASRA GULF



(B)
EVAPORATION



LEGEND:

- (Symbol indicate addition to Derband-Khan-Dolan system.)
 B Basra Reservoir
 F Fish Reservoir (4 millions dead storage unless followed by 2M, indicating 2 millions dead storage)
 M Mad Tashir Reservoir
 M₁ Eti Mawl project (irrigation without Jazira Project)
 M₂ Eti Mawl project (irrigation with Jazira Project)
 Subscript figures for M, B, and F indicate top elevation for irrigation storage, in meters above C.T.S. datum
 Subscript figures for W indicate level for irrigation outlet, in meters above C.T.S. datum
 Each plotted point represents the results of a monthly system operation study

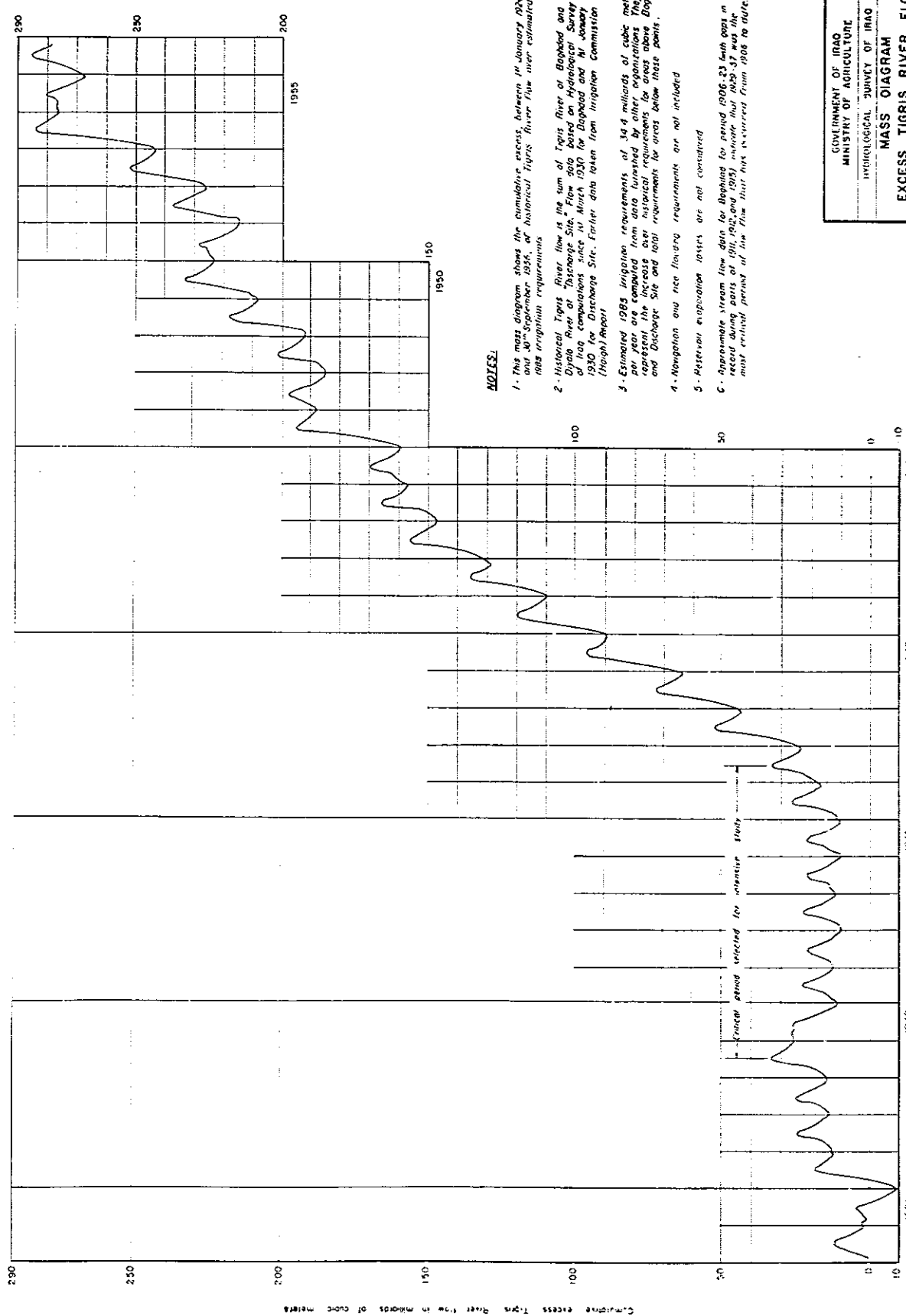
NOTES:

1. Evaporation losses and waste to the Gulf for each reservoir combination are for the highest level of irrigation that the particular combination can support with tolerable shortages.
2. Losses represent average in Tigris River system for period June 1929 through May 1937.
3. Evaporation based on 2 meters per year for each reservoir.
4. Water wasted to the Gulf is flow of usable reservoirs part not in excess of irrigation and navigation requirements (Average discharge of 108 millions from Adham and Lower Diyala Rivers not included).
5. Mad Tashir Reservoir considered to be in system only if used for irrigation storage.

PRINTS		BY	DATE	REVISION
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2	100	10/1/37	10/1/37	2
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4	100	10/1/37	10/1/37	4
5	100	10/1/37	10/1/37	5
6	100	10/1/37	10/1/37	6
7	100	10/1/37	10/1/37	7
8	100	10/1/37	10/1/37	8
9	100	10/1/37	10/1/37	9
10	100	10/1/37	10/1/37	10
11	100	10/1/37	10/1/37	11

GOVERNMENT OF IRAQ	
MINISTRY OF AGRICULTURE	
HYDROLOGICAL SURVEY OF IRAQ	
WATER LOSSES	
IN TIGRIS RIVER BASIN	
1929-1937	
UNION ENGINEERING CO. INCORPORATED IN CHICAGO	IRAC ASSOCIATION
CHICAGO, ILLINOIS	DATE
10-1-37	10-1-37
610-24	610-24

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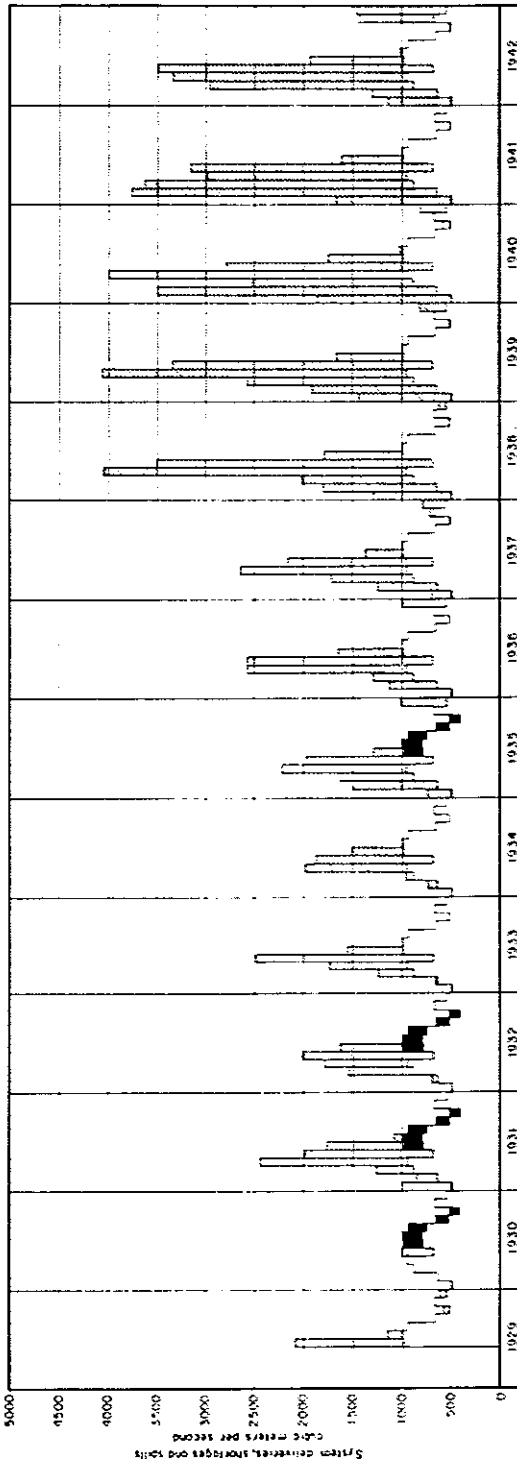
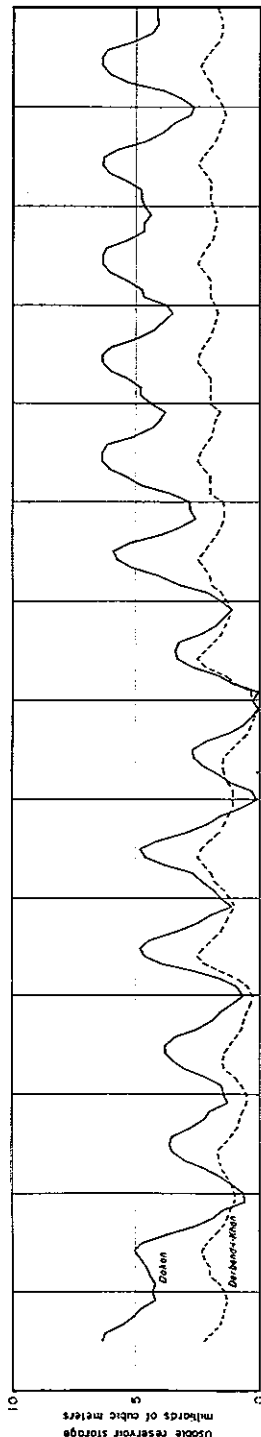
Notes:

1. This mass diagram shows the cumulative excess, between 14 January 1934 and 20 November 1955, of historical Tigris River flow over estimated 1985 irrigation requirements.
2. Historical Tigris River flow is the sum of Tigris River at Baghdad and Diyala River at Tashgarh Site. Flow data based on Hydrological Survey of Iraq commissions since 14 March 1930 for Baghdad and Al Jawah 1930 for Tashgarh Site. Earlier data taken from Irrigation Commission (though Report
3. Estimated 1985 irrigation requirements of 34.4 milliards of cubic metres per year are computed from data furnished by other organizations that represent the increase over historical requirements for areas above Baghdad and Discharge Site and total requirements for areas below those points.
4. Nonpoint and rice flooding requirements are not included
5. Reservoir evaporation losses are not considered
6. Approximate stream flow data for Baghdad for period 1906-23 with 1905 as record during parts of 1910, 1912, and 1913 indicate that 1909-37 was the most deficient period of low flow that has occurred from 1906 to date.

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ
MASS DIAGRAM
EXCESS TIGRIS RIVER FLOW
1985 CONDITIONS
TIGRIS RIVER FLOW, CD - TIGRIS, UP-TO IN CHANNEL,
CD 10000
LONDON
BY ASSOCIATION
DATE 1985 NO 800, 3
BAGHDAD, IRAQ

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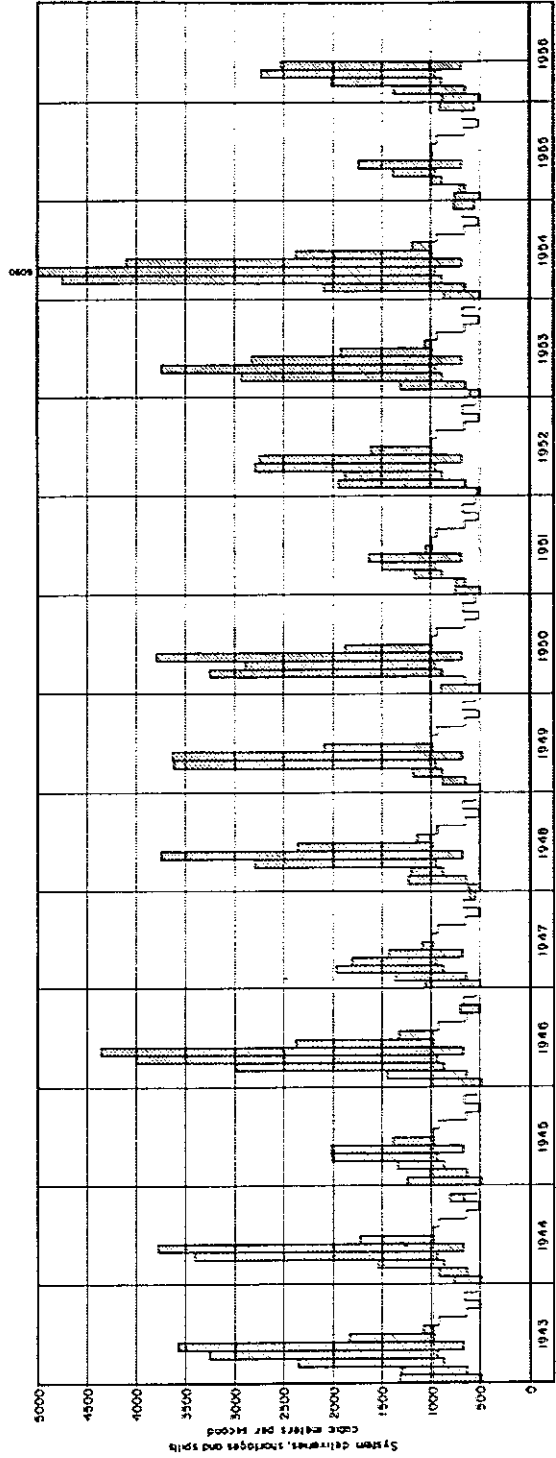
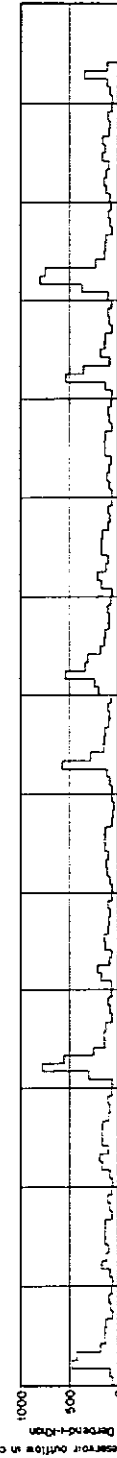
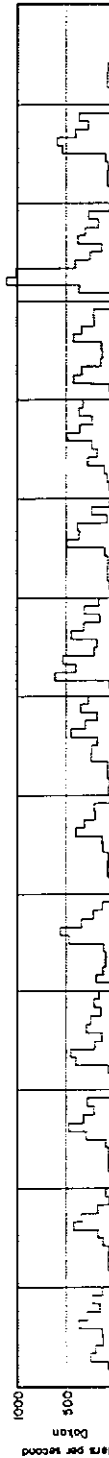
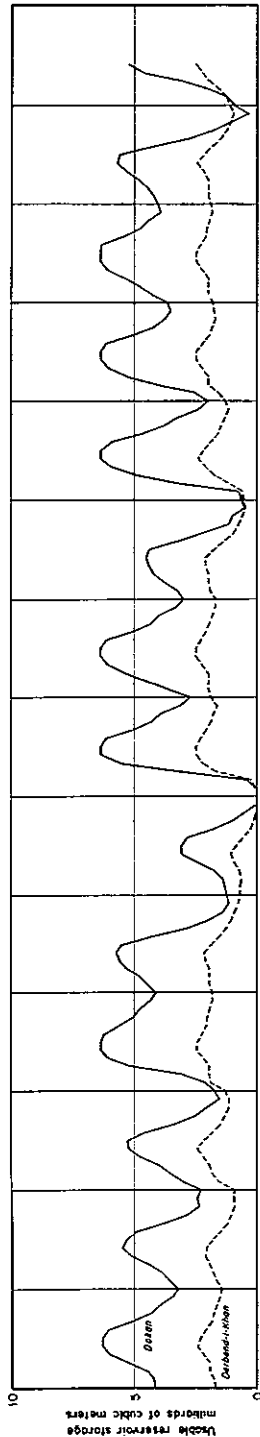


LEGEND
 ■ System shortages
 □ System spills
 ▤ System deliveries

NOTES

- 1 - This irrigation operation study is for the existing two-reservoir system composed of Dabon and Dabon-Atman. The study is for the purpose of determining the system operation.
- 2 - Irrigation deliveries are the maximum firm yield of the system with available storages of 200 million cubic meters. The system is operated from June 1929 through May 1937. System-wide irrigation shortages are confined to the June through October period.
- 3 - Dabon-Atman Reservoir is operated primarily for the benefit of Diyala River lands. Other lands are supplied from Dabon Reservoir.
- 4 - A line canal capable of delivering 30 cubic meters per second from the Lesser Zab River to the Diyala River is assumed in this study.
- 5 - System spills are spills of usable water. Flows from the Atman and Middle Diyala Rivers are assumed to be suitable for irrigation and therefore would be spilled, but are not shown on this exhibit.

GOVERNMENT OF IRAQ MINISTRY OF AGRICULTURE HYDROLOGICAL SURVEY OF IRAQ	
IRRIGATION OPERATION STUDIES EXISTING RESERVOIR SYSTEM	
MOUSTA TASHKEENI & CO. CHICAGO, ILLINOIS	ENGINEERING & ARCHITECTS IN ASSOCIATION CHICAGO, ILLINOIS
June 1942	600-B2



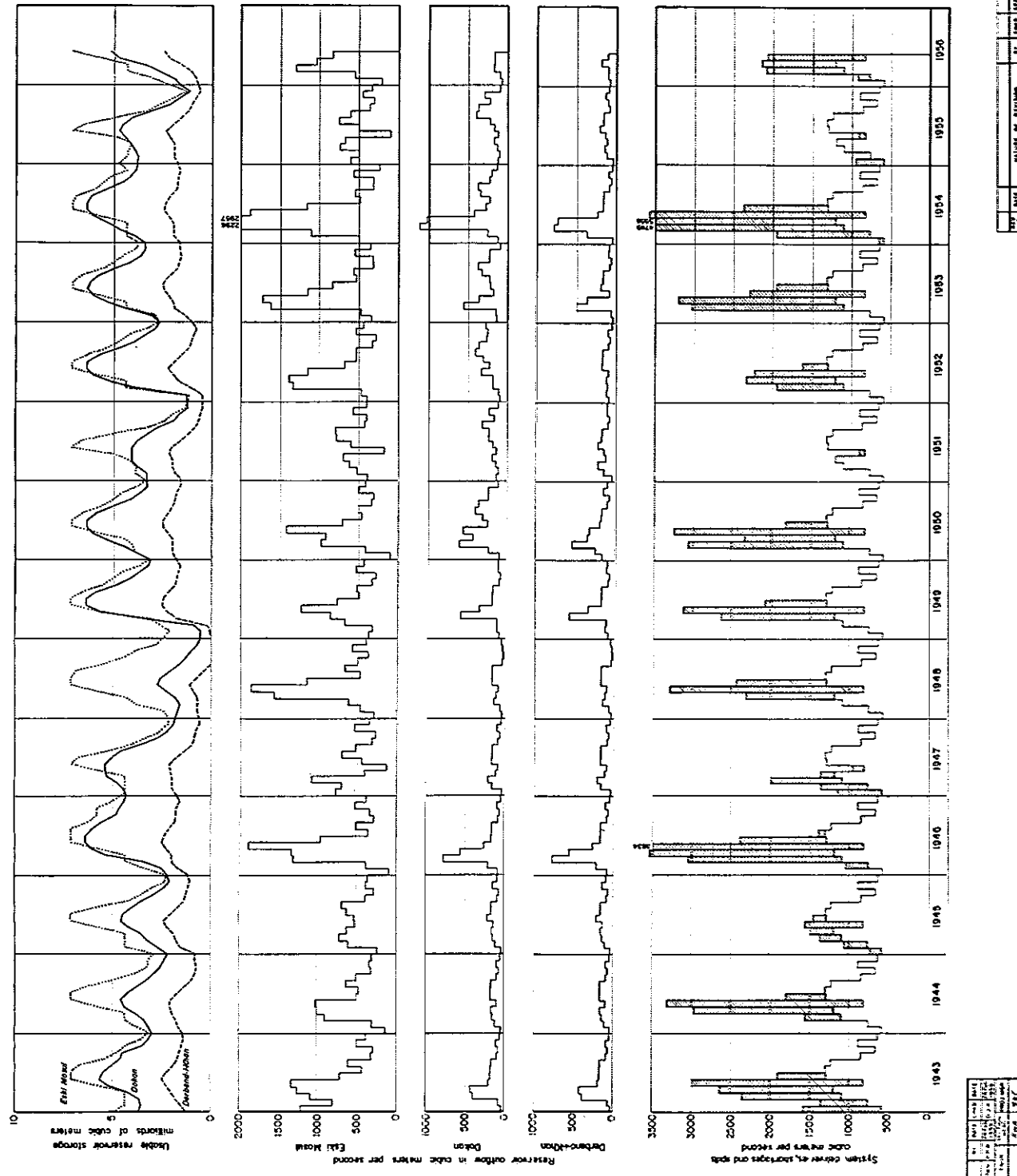
Notes and legend on sheet 1.

GOVERNMENT OF IRAQ MINISTRY OF AGRICULTURE HYDROLOGICAL SURVEY OF IRAQ	
IRRIGATION OPERATION STUDIES EXISTING RESERVOIR SYSTEM	
HAZIZA ENGINEERING CO. CHICAGO	ENGINEERING ASSOCIATION LONDON
DATE 24 June 1955	WORK NO. 680-03

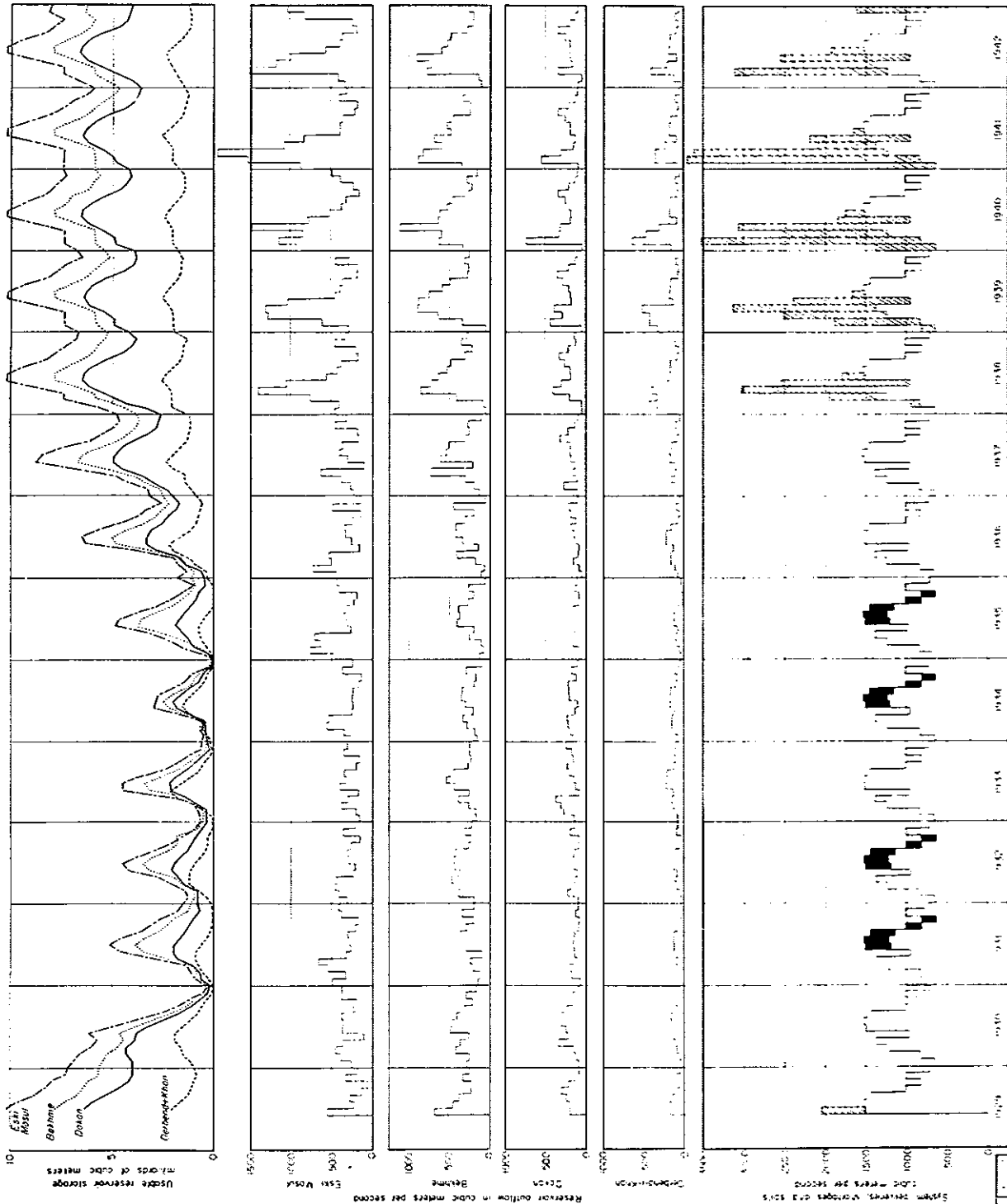
Year	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955
System deliveries, shortages and spill (cubic meters per second)	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
Usable reservoir storage (millions of cubic meters)	10	10	10	10	10	10	10	10	10	10	10	10	10
Reservoir outflow (cubic meters per second)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

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-329-



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NOTES:

1. This irrigation operation study is for a low-reservoir system including Eski Mosul and high Bekhme dams, and is presented in the form of a preliminary system operation.
2. Irrigation deliveries are the maximum firm yield of the system, with tolerance shortages of 25 percent in four years of the critical period, June 1929 through May 1937. System-wide irrigation shortages are confined to the June-through-October period.
3. Irrigation deliveries are operated primarily in the branch of Dukan River lands. Other reservoirs are maintained at equal reservoir levels of their capacity, insofar as possible.
4. A first canal capable of delivering 50 cubic meters per second from the Lesser Zab River to the Lesser Zab River, and a second canal capable of delivering 25 cubic meters per second from the Greater Zab River to the Lesser Zab River, are assumed in this study.
5. System spills are spills of usable water flows from the Bekhme and Middle Dukan rivers are assumed to be available for irrigation and are shown as spills, but are not shown on this exhibit.

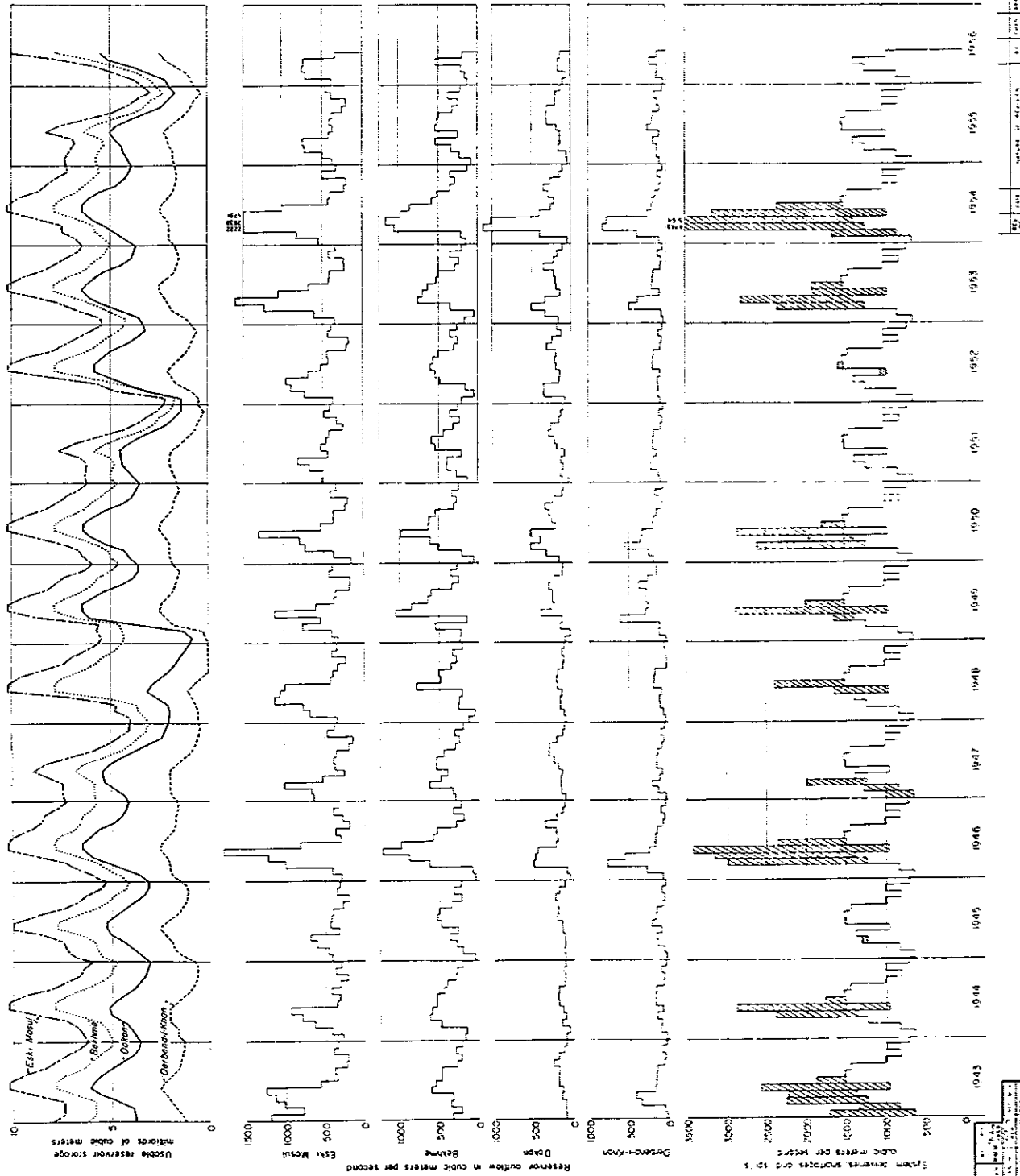
LEGEND

- System shortages
- - - System spills
- ... System deliveries

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL DIVISION
IRRIGATION OPERATIONS
EXISTING SYSTEM PLUS
HIGH ESKI MOSUL & HIGH BEKHME
UNITED STATES OF AMERICA
WASHINGTON, D.C.
1942

- 232 -

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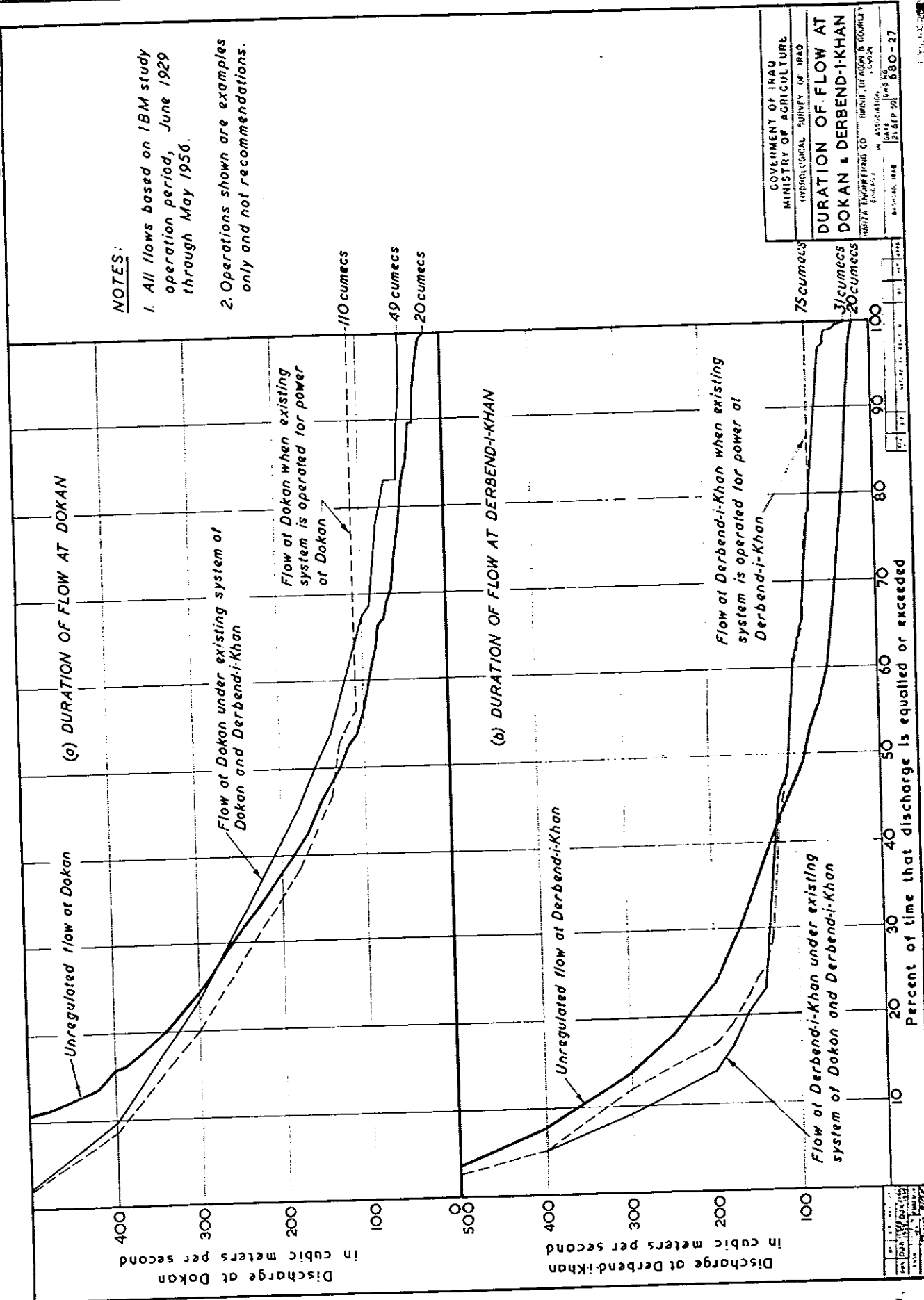


Notes and legend on sheet 1

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ
IRRIGATION OPERATION
EXISTING SYSTEM PLUS
HIGH ESKI MOSUL & HIGH BEKHME
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ
TEHRAN, IRAN
PLANNING DIVISION
JANUARY 1957
MAY 1957
680-6

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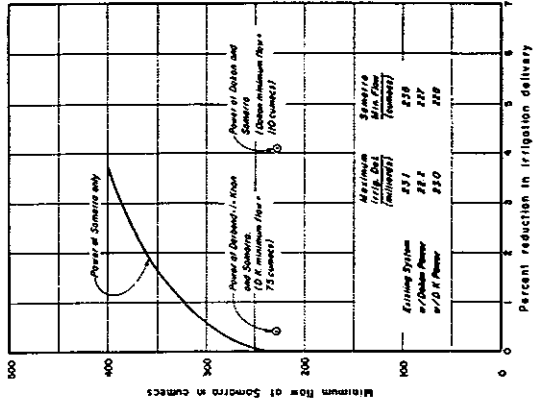
-233-



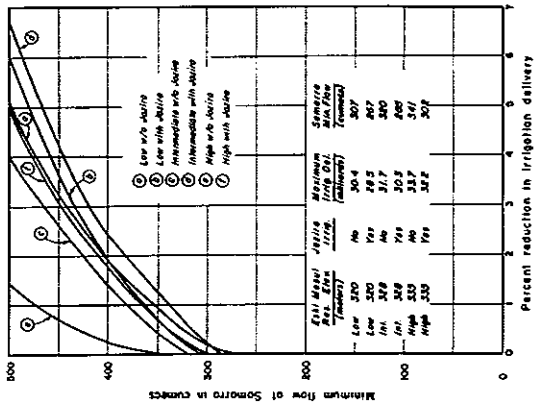
NOTES:

1. All flows based on IBM study operation period, June 1929 through May 1956.
2. Operations shown are examples only and not recommendations.

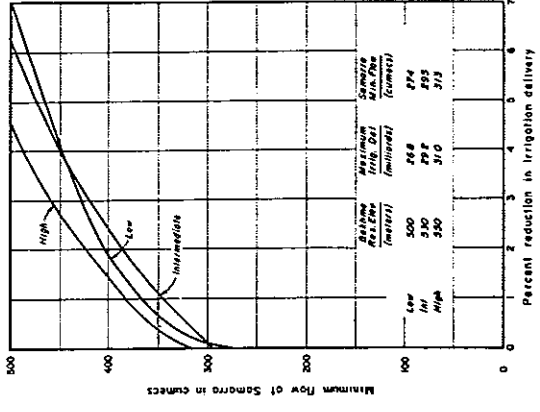
GOVERNMENT OF IRAQ	
MINISTRY OF AGRICULTURE	
HYDROLOGICAL SURVEY OF IRAQ	
DURATION OF FLOW AT DOKAN & DERBEND-I-KHAN	
PROJECT NO.	21 SEP 59
DATE	1959
BY	680-27



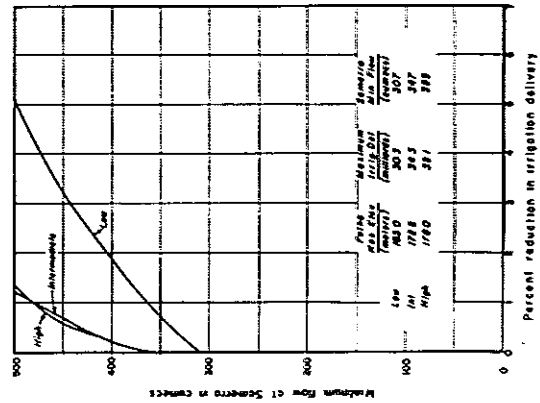
(a) EXISTING SYSTEM, DOKAN AND DERBEND-LIHAN



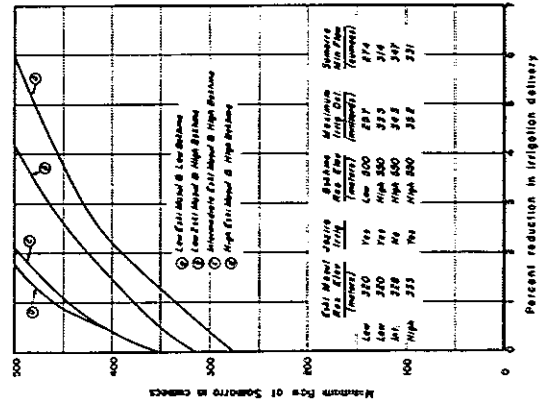
(b) EXISTING SYSTEM PLUS ESKI MOSUL



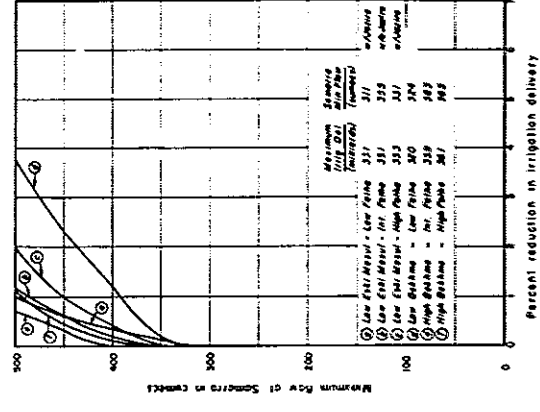
(c) EXISTING SYSTEM PLUS BEHME



(d) EXISTING SYSTEM PLUS FATHA



(e) EXISTING SYSTEM PLUS ESKI MOSUL AND BEHME



(f) FOUR RESERVOIRS INCLUDING FATHA

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
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